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THE RED BEDS OF NORTHERN COLORADO[1]

JUNIUS HENDERSON
University of Colorado, Boulder, Colo.

The perennial problem of the age of the so-called Red Beds of Colorado received some attention from the State Geological Survey during the field season of 1907, and owing to the uncertainty as to when the results may be published by the survey, it is deemed best at this time to give to the public a brief statement of the important facts. These beds were designated Jura-Trias by the early surveys, chiefly on account of lithologic resemblances to formations found elsewhere. Since it became evident that at least the lower portion in many places is much earlier, the term Red Beds has come into general use. Our work on these formations in 1907 was confined to the foothill region north of Boulder. At the northern boundary of Colorado we found a chert concretion zone containing *Spirifer centronatus* Winchell, *Cranaena subelliptica* var. *hardingensis* Girty, and *Spiriferina solidirostris* White, a fauna which is considered Mississippian and is found on the east side of the Front Range at Canyon City and elsewhere. The first-named species and others of like age were long ago reported from that region, but the record had little value because the position in the formation was not given. We traced the chert zone for eight or nine miles southward, finding it everywhere within a few feet of the contact of the conglomerate with the granite and uniformly containing fossils, but found none farther south. The coarse sandstone and conglomerate series in which this fossiliferous zone occurs appears

[1] By permission of the State Geologist of Colorado.

to be stratigraphically continuous with the Fountain formation in the Boulder District as defined by Dr. Fenneman,[1] who correlates it with the Fountain of the Colorado Springs region. We have traced the formation in the field the entire distance from the Wyoming line to Boulder and find no reason to doubt that the horizon containing the chert fossils is the equivalent of the base of the Fountain as represented at Boulder, or possibly even much higher than the base as it occurs immediately north of Boulder, where the formation is much thicker than near the Wyoming line.

In limestones at a much higher horizon we found a Pennsylvanian fauna (tentatively considered older than Knight's so-called "Permian" of Wyoming), consisting of *Productus cora* D'Orb., *P. nebrascensis* Owen, *Spirifer rockymontana* Marcou, *Squamularia perplexa* McCh., *Derbya* n. sp. ?, *Phillipsia* aff. *major* Shumard, *Myalina swallowi* McCh., abundant crinoid stems and others. These limestones were said by Darton[2] to pass into the Fountain conglomerates in traveling southward. Of this we are by no means certain without further investigation, but they seem certainly to belong at the very top of the Fountain or base of the overlying Lyons formation of Fenneman's bulletin. These limestones nearly disappear at the Cache la Poudre, and a little work just north of that stream is necessary to determine their exact position. We have traced the contact of the Fountain and Lyons all the way from the northern line of the state to Boulder except two or three miles between the Cache la Poudre and Owl Canyon, and believe the Ten Sleep sandstone of Darton's paper to be the stratigraphic equivalent of Fenneman's Lyons.

It seems very clear that all of the Fountain sandstones and conglomerates of northern Colorado are Carboniferous, the base being probably Mississippian (certainly so in the northern portion of the field) and the upper portion possibly as late as Pennsylvanian. It also seems likely that the Lyons is Pennsylvanian.

The fossils were, through the kindness of Dr. T. W. Stanton, of the United States Geological Survey, submitted to Dr. G. H. Girty, whose determinations are followed in this paper.

[1] N. M. Fenneman, *Geology of the Boulder District, Colorado*, U. S. Geol. Sur., Bull. No. 265, 1905.

[2] N. H. Darton, *Geology and Underground Water Resources of the Central Great Plains*, U. S. Geol. Sur., Professional Paper No. 32, 1905.

GLACIAL DRIFT UNDER THE SAINT LOUIS LOESS

J. ANDREW DRUSHEL
Teachers College, St. Louis, Mo.

Glacial drift in the vicinity of St. Louis seems to have been described first by Professor A. H. Worthen, in 1866.[1] In 1890, Professor G. Frederick Wright[2] reported glacial drift in the following localities within the city limits: (1) Near Forest Park, on the road to Ferguson, beneath 20 feet of loess was a bed of gravel 2 or 3 feet thick, which contained granite and other pebbles two to three inches in diameter, some finely striated; (2) at Hyde Park a similar section was seen; (3) in the vicinity of Shaw's Garden. Loess had been removed for brick making, uncovering extensively a gravelly stratum which contained many granite pebbles. Striae were found on angular limestone fragments. The elevation was 150 feet above the Mississippi River.

H. A. Wheeler, in a paper "On Glacial Drift in St. Louis," in 1895,[3] reported blue glacial clay or till 12 feet thick, at West Pine Boulevard and Taylor Avenue, extending westward to Euclid, underneath 10 to 15 feet of loess. The diameter of the bowlders is said not to exceed one foot. Among the erratics reported were red and gray granite, diorite, dolerite, and quartz-porphyry.

In 1896 James E. Todd[4] described bowlder clay in St. Louis. His section may still be seen on Laclede Ave. near Sarah St. The till is 8 feet thick, "a reddish brown or a waxy red clay," containing granite and other foreign pebbles. The overlying loess is 16 feet thick.

Frank Leverett, in his monograph on the *Illinois Glacial Lobe*,[5] reported deposits of glacial derivation underlying the loess for a few

[1] A. H. Worthen, *Geology of Illinois*, Vol. I, p. 314, 1866.

[2] G. F. Wright, "The Glacial Boundary in Western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois," *Bulletin 58, U. S. Geological Survey*, p. 72, 1890.

[3] H. A. Wheeler, "On Glacial Drift in St. Louis," *Transactions of the St. Louis Academy of Science*, Vol. VII, pp. 121, 122, 1895.

[4] J. E. Todd, *Missouri Geological Survey*, Vol. X, pp. 162, 163, 1896.

[5] F. Leverett, *The Illinois Glacial Lobe*, Monograph XXXVIII, pp. 64, 71, 1899.

miles back from the Mississippi River in northern St. Louis County. While he recognized the glacial nature of the deposits, he favored the

FIG. 1.—Exposure of loess and underlying till on the south side of the quarry at Grand Ave. and Rutger St. 1, St. Louis limestone, much decayed at the top; 2, bowlder clay; 3, loess.

idea that they were water-laid, basing his opinion on the water-worn appearance of the pebbles and cobbles, and the presence of pebbles

which had evidently come from outcrops in Calhoun and Lincoln counties, a few miles up the valley. "It remains an open question whether the ice sheet reached into northern St. Louis County from the Illinois side of the river."

So far as the writer knows, the foregoing is the sum total of reported investigation of a glacial drift under the St. Louis loess. It is the purpose of this paper to present additional evidence of a true drift in the above-mentioned region.

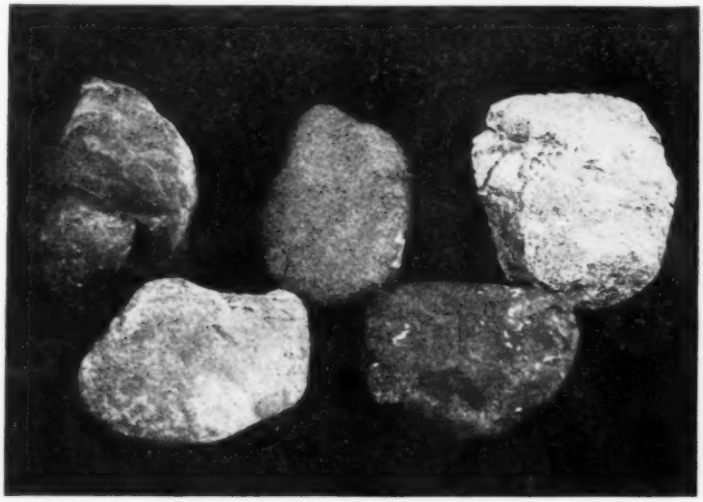

FIG. 2.—Pebbles from the bowlder clay at St. Louis. *A* and *B*, quartzite; *C* and *D*, greenstone; *E*, chert. Reduced to less than three-eighths natural size.

At the quarry near Grand Ave. and Rutger St. may be seen a section of till resembling the material described by Todd. On the south side of the quarry the drift sheet is 4 feet thick, and lies on the deeply decayed St. Louis limestone. On the west side of the quarry the till is from 2 to 3 feet thick. The overlying loess has a thickness of from 12 to 17 feet. In places the contact between the loess and the clay is sharply defined (see Fig. 1). This clay differs from the loess in color, texture, and composition. It is red rather than buff colored, compact, and very sticky when moist. The upper portion

of it has a sheet of small water-worn pebbles. Occasional subangular and planed bowlders are found in the clay beneath the pebbly sheet. The largest pebble found in this section by the writer is a chert shown in Fig. 2, *E*. Its dimensions are 13 by 10 by 8 centimeters.

On Meramec St., north of the Workhouse quarry, there is an outcrop of till on the south and east faces of the bluff. The deposit lies on the St. Louis limestone, and beneath loess 20 to 25 feet thick. The line of contact between loess and till is a sharp one. With the possible

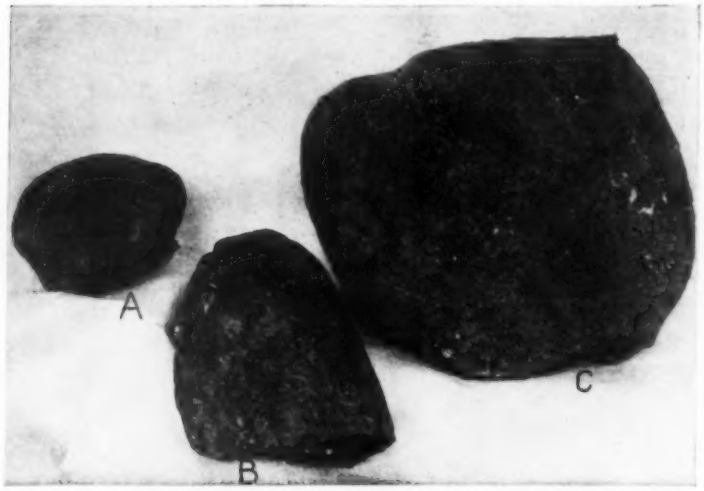

FIG. 3.—Pebbles from the bowlder clay of St. Louis. *A*, ferruginous chert; *B*, felsite; *C*, sandstone. Reduced to about one-fourth natural size.

exception of Wheeler's section at West Pine Boulevard and Taylor Ave., the material at Meramec St. is more pebbly and bowldery than any till heretofore described as lying beneath the St. Louis loess. The sheet in the Meramec St. section is 2 to 3 feet thick, and contains bowlders a foot in diameter. Bowlders from 8 to 12 inches are quite numerous. Some of them show both planed and polished surfaces. Several bowlders of granite, including a biotite granite of medium texture and others of a coarse, pegmatitic nature, have been found here. They not infrequently show planing, but are always much weathered inside.

Several pebbles of characteristic subangular shape and of a composition which shows them to be erratics are shown in Figs. 2 and 3. Fig. 3, *A*, is a ferruginous chert. It bears a resemblance to pebbles in a conglomerate at the base of the Sioux quartzite of southern Minnesota and northern Iowa. Cherts of this sort are also found, however, in the Mesabi and Penokee iron ranges of northern Michigan. Fig. 3, *B*, is a planed and polished pebble of dark-blue felsite which contains phenocrysts of feldspar and quartz. Fig. 3, *C*, is a sandstone with hematite cement, approaching a quartzite. In Fig. 2, *A* and *B* are quartzite resembling that at Sioux Falls, Ia.; *C* and *D* are medium-grained greenstone, planed on three faces. Pebbles and bowlders representing the following rocks are found in this section: coarse sandstone, almost a quartzite, with silica and limonite cement; sandstone with hematite cement; quartzite; vein quartz; quartz porphyry; felsite; greenstone; biotite granite; pegmatite. While all these varieties might have come either from the southern Minnesota district or the Lake Superior district, it seems rather probable that the drift came from the former direction. This district is nearer than that of northern Michigan; and a southward direction of transportation would agree with Leverett's observations of pebbles from Calhoun and Lincoln counties.

From Meramec St. southward for several blocks exposures of bowlder clay of varying thickness may be seen. Near the Hoffman-Hogan quarry is an outcrop resembling the one at Grand Ave. and Rutger St., described in this paper. Rhyolite, granite, and diabase pebbles have been found by the writer in these exposures.

While it is possible that in certain places the thin sheet of gravelly material under the St. Louis loess is glacial gravel, as described by some authors, rather than till, the sections described in this paper are without doubt true bowlder clay. The variety in composition of the pebbles and bowlders indicates collection from distant and scattered sources, and transportation by an ice sheet. The presence of many subangular pebbles with smooth and planed sides, associated with pebbles of less characteristic shapes, the heterogeneous mixture of bowlders, pebbles, and fine clay, and the compactness and general consistency of this clay, are all indicative of till rather than of a water-made deposit. This sheet of drift has been observed by the writer

in the northwest, central, and southeast portions of the city. Considering these sections and those previously described, it seems that the sheet underlying the St. Louis loess is true glacial drift. It seems not unlikely that in other places as well as here the old drift sheets beneath the loess extend farther south than they have heretofore been fully recognized

THE JAPANESE VOLCANO ASO AND ITS LARGE CALDERA[1]

ROBERT ANDERSON
Washington, D. C.

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BRIEF DESCRIPTION

Aso-san is a volcano in the center of Kiushiu, Japan, within twenty-nine miles of the western, and forty-five miles of the eastern, coast of the island. It consists of a huge mound-shaped cone on the summit of which is sunk an oval bowl measuring about ten miles in width, fourteen miles in length, and 1,000 to 2,000 feet in depth, the bottom being some 1,500 feet above sea-level. Within this bowl a range of mountains, attaining an altitude above sea of 5,600 feet and overtopping the rim more than 2,000 feet, runs from east to west across its short diameter and divides it into 2 crescent-shaped basins. On the summit of this dividing range is a low modern cone with active

[1] Read before the Geological Society of Washington, January, 1907.

crater; and at the foot of the range on either side a fairly level plain stretches off to a steep mountain wall that surrounds the bowl. At only one point a break occurs in this wall. The central range is so high and broad, and so completely shuts off the inclosed plain on the south from the one on the north, that one does not at once recognize the two plains as parts of a single great oval floor. But each of the basins is so perfectly the complement of the other that little doubt can exist of their being the two halves of a large crateral depression partitioned off by mountains of subsequent growth. The bowl has a typical caldera form, and it has most probably originated through the subsidence of a formerly overlying mountain mass. It is one of the very largest, if not the largest, of the craters known on this planet, and without doubt the largest having such perfect preservation.

SOURCES OF INFORMATION

The observations upon which this article are based were made in the spring of 1905, when I made a visit to the volcano and lived for nearly two weeks within the caldera.[1]

Little has been known or published concerning Aso-san. John Milne many years ago made a hasty visit to it and published a narrative and descriptive article in the *Popular Science Review*.[2] He has also discussed the history of the eruptions of the new crater and noted other features of the volcano in the *Transactions of the Seismological Society of Japan*.[3] Aso-san is briefly described by Edmund Naumann in his paper "Ueber den Bau und die Entstehung der japanischen Inseln,"[4] and there is an article in Japanese on the subject in the Tokio *Journal of Geography*, written by T. Iki.[5]

No detailed maps are available upon which to base statements regarding Aso. The altitudes and other measurements here given are approximate but are based on careful estimates, on barometric measurements, and on general maps of Kiushiu. The accompany-

[1] In company with my brother, Malcolm Anderson, and friend, Kiyoshi Kanai, to both of whom I am indebted for photographs and information.

[2] New Series, Vol. IV, No. 16, October, 1880.

[3] Vol. IX, Pt. II, 1886.

[4] Berlin, R. Friedländer & Sohn, 1885.

[5] Published by the Tokio Geog. Soc.; Vol. XIII, No. 149, April, 1901.

ing diagram is largely from memory and is intended merely to convey a general idea of the caldera.

GEOLOGY OF KIUSHIU

The island Kiushiu, which covers about 17,000 square miles, has a foundation of rocks of Paleozoic age and possibly some belonging to the Archaean. These are largely sedimentary, and frequently metamorphic; but associated with them are many varieties of igneous rocks. Less altered strata of supposed Mesozoic age, but possibly

FIG. 1.—Sakura-jima, an andesitic cone of medium slope, in the bay of Kagoshima at the southern end of Kiushiu. Its last eruption was in 1779. Its altitude is 3,850 feet.

in part representative of the early Tertiary, overlie these extensively; and fossiliferous, much-disturbed Tertiary formations occur in numerous relatively small detached basins. Over these basement rocks a superstructure of eruptives has been built up during the Quaternary, having probably been begun before the close of Tertiary time. About one-half of the island is now covered by these volcanic rocks. In some places the covering has the nature of a thin layer of ash or volcanic mud or lava over the old surface, whereas in others it has a great thickness. The whole of the north-central part of the

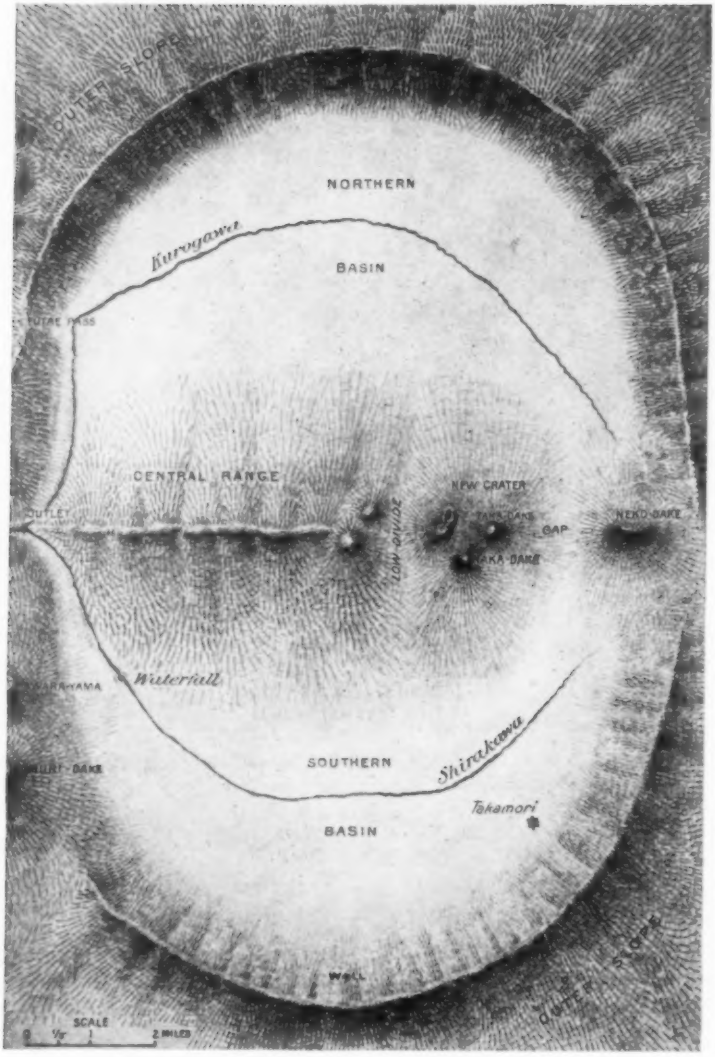

FIG. 2.—Rough diagram of the Aso caldera.

island and much of the southern part is volcanic. The Japanese geologists count twenty volcanoes in Kiushiu, including two that form small islands near the coast on the south. The period of volcanic construction extends into the present—eight of the twenty volcanoes being still living—but the general activity seems to be on the decline. The volcanic forces must have reached their climax sometime during the middle Quaternary, to judge from the amount of erosion that has taken place since the greatest outpourings occurred; and it is probably from this period that the long since extinct crater of Aso dates. In its prime Aso doubtless held a position of pre-eminence among the volcanoes and mountains of Kiushiu, as is indicated by the extent of territory that is covered by material derived from its eruptions, and by the grandeur of the scale upon which the crater was built and the probability that a cone formerly rose to a great height above it. Its present peaks are surpassed by a few others in the island, the highest of which is the non-volcanic mountain Sobo-san, 6,600 feet in altitude.

APPROACH TO THE CALDERA

Aso-san may be most easily reached from Kumamoto, a city situated on the coastal plain near the western coast of Kiushiu. From there a road runs up into the mountains and down into the caldera, which is about twenty miles away. The volcano does not form a prominent cone as seen from this side and appears merely as a high portion of the mountain mass that occupies the island's interior. The caldera becomes apparent only on an approach to its very edge, or from the summit of one of the high mountains within a score of miles of Aso. From such a summit one looks down upon it and obtains an impressive view of the huge bowl and the high volcanic peaks that spring from within it.

THE FLOOR

Viewed broadly, the floors of the two basins into which the caldera is divided are level plains lying at the same elevation. They slope gently upward from west to east. On the east they break into low sweeping ridges and knolls that rise gradually and merge with the wall and central range, which are there convergent. (See Fig. 3). Throughout the centra portion of each of the two basins the floor

Fig. 3.—Panorama of the southeastern portion of the caldera. Looking north and northeast from near Takamori. Naka-dake and Taka-dake on the left, Nekodake in the center, and the ring wall on the right. Photo by Malcolm Anderson.

except for gentle undulations, is almost level and has an average elevation of about 1,500 feet. On the inner side of each it slopes gently up to the central range, and on the outer side to the wall. Each half of the caldera is traversed by a stream that follows a shallow curving course from east to west. The stream in the southern basin is called "Shirakawa" (*kawa* or *gawa* means river); that in the northern, the "Kurogawa." The usually dry, branching, tributary runnels in the upper course of the former are shown in the middle foreground of Fig. 3. The Kurogawa carries considerably more water than the former and is worthy to be called a small river. (See Fig. 5.) These streams unite around the western end of the central range, which just fails to reach the wall there, and flow out through a canyon or barranco. The single stream thus formed, called the Shirakawa, runs westward down the mountains and across the Kumamoto plain to the sea. The point of outlet is at an elevation of about 1,000 feet above the sea, and on approaching it the streams leave their gentle

course over the comparatively flat plain and tumble down to their junction at the outlet with gradients of 4 to 8 per cent. or more. The northern one makes the descent the more rapidly. The southern one on leaving the upper level of the floor drops over a picturesque waterfall.

The northern basin appears to be larger and rounder than the southern one and its floor is even more level. Small parts of it were

FIG. 4.—A portion of the ring wall, looking southwest across the cultivated floor of the southern basin. The wall in this portion is considerably worn. The town of Takamori shows in the distance on the left. Photo by Malcolm Anderson.

flooded or marshy during April, 1905. Several small isolated and fairly steep hills rise out of the northern basin. They were not observed closely but looked as if they were composed of the same material as the wall.

The surface deposits of the floor appear to be chiefly fine sandy material and coarse yellow sand and gravel in horizontal layers, covered with black, slightly sandy soil. The deposits were probably

formed by a mingling of the products of eruptions and erosion. The low slopes and hillocks where the plain rises into the wall are, as far as observed, composed of lava both vesicular and compact, and it is most likely that the floor within no great depth below the surface is composed of the same material.

The floor of the caldera is everywhere cultivated, and supports a population that may be roughly estimated as amounting to at least 5,000 people. Many villages and groups of dwellings are scattered over the plain, and clusters of trees stand here and there. The whole scene is a remarkable one, being especially brilliant when the spring crops, which consist chiefly of green wheat and mustard with yellow flowers are maturing. There is a legend that the mountain-girt bowl of Aso was once occupied by a lake, until the god of the mountain kicked a hole in the wall where the present outlet is and allowed the water to flow out. There may have been in former times flooded areas of more wide extent than those noted above, but it does not seem probable that a real lake ever occupied the caldera.

THE WALL

The caldera has an oval shape and its rim forms a smooth sweeping curve around the whole circumference, broken only at the cleft on the west where the streams pass out, and on the east where the wall is joined by the descending slope forming the extremity of the central range. The curvature of the wall is so slight that it appears at a glance like the face of a straight mountain range. On the basis of a rough estimate it may be said that the average slope from the floor to the top of the wall would nowhere exceed 25 or 30°, although rocky almost vertical precipices occur at points on its face. The wall is furrowed by gulches that have in places eaten back to the summit and notched the skyline of the rim. In general, however, its top is fairly even. Between the gulches sharp ridges run out into the floor. The wall varies in appearance from point to point, and the ridges and prominences on its face have a variety of picturesque shapes. The wall of the southern basin, exposed to the north, is much more worn than that of the northern one. Forms resembling the remains of terraces appear in places. The lower portion of the wall has a gentle slope, and at some places is deeply soil-covered

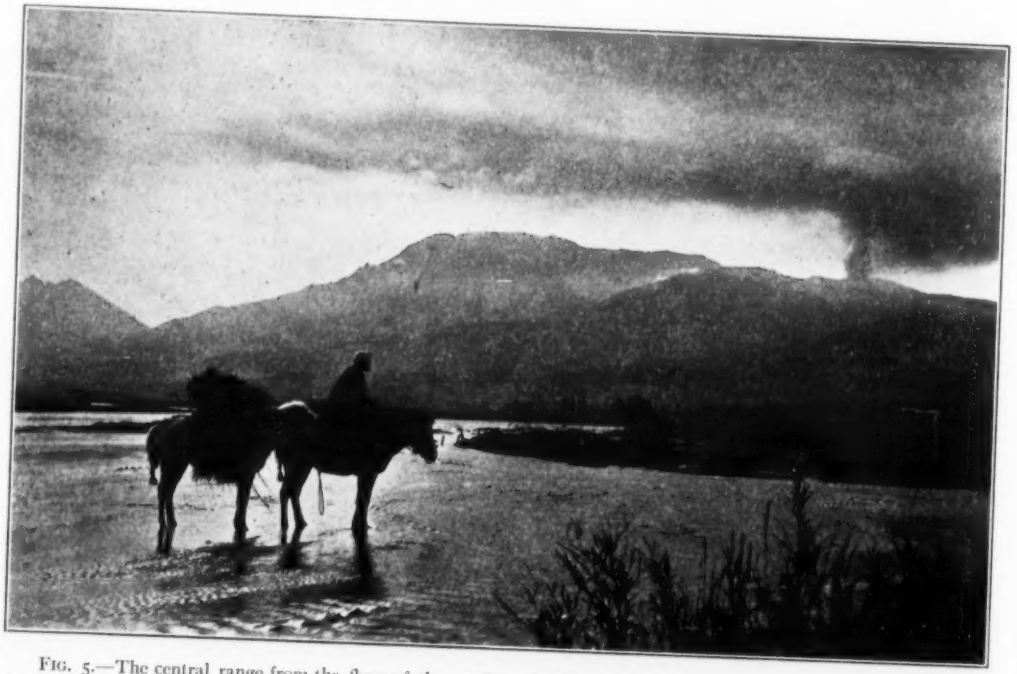

FIG. 5.—The central range from the floor of the northern basin. In the foreground flows the Kurogawa; on the right a vapor cloud rises from the modern crater; in the center is Taka-dake, 4,000 feet above the foreground; and on the left is a portion of Neko-dake. Looking southeast.

and supports a fine grove of trees. The higher portion is precipitous and exposes best the material of which it is made. It is formed of roughly bedded flows of basaltic andesite, interbedded and intermingled with mixtures of vesicular lava, scoriae, pumice, and volcanic sand. The lava predominates, and the harder layers project with vertical rocky faces, while between them softer zones have weathered way into débris slopes. The height of the wall is on the average about 1,300 to 1,500 feet. It decreases toward the eastern side owing to the gradual rise of the floor in that direction, but increases at some points, as on the southwest and west sides, where mountains break the regularity of the horizon line.

The only opening in the ring wall is the barranco on the eastern side through which the streams have their outlet. Cliffs of roughly columnar lava form the sides of this gorge up to a height of several hundred feet and are continued upward by densely wooded slopes that rise over 1,500 feet above the stream bed. The span of the canyon where it begins to widen out above the cliffs is less than half a mile.

Probably the next lowest point upon the rim is at a point three miles north of the outlet, where the "Futaetoge" (*toge* means "pass"), which has an elevation of about 2,500 feet above the sea, is less than 1,000 feet above the caldera floor. Another stream running down the outer slope to the sea heads at this low point. The highest portion of the watershed on the rim is on Tawara-yama and Kamuri-dake, two mountains that form the wall at the western end of the southern basin. They rise 2,000 to 2,700 above the floor of the caldera. The former is between two and three miles south of the outlet of the streams, the latter four miles or more. The summit of each and the high ridge connecting them is about two miles back from the floor.

THE CENTRAL RANGE

The ridge or range that divides the caldera is, properly speaking, Mount Aso. From the floor on the south, or the one on the north, it appears as a massive rugged barrier the summit of which is roughened by several dominating peaks. (See Figs. 3 and 5.) Looking up at it from either basin one would never imagine the existence of a second and almost identical pit with level floor and encircling outer wall at

its base on the opposite side. It is only from one of the peaks in the range or from a distant mountain top that a conception of the whole as a unit and as a single vast caldera may be obtained.

There are three main peaks, all along the eastern half of the range. The western end is lower, has less bold outlines, and declines gradually toward the west. The most striking of the peaks in the range is Neko-dake at the very eastern end. (The word *dake* which forms

FIG. 6.—Recent-looking lava with smooth flow structure, high on the south side of Naka-dake. Looking south toward the southern wall, which shows dimly far across the caldera.

part of the name of many Japanese mountains means "peak.") Its slopes have the graceful curving outlines characteristic of volcanic cones and its summit is serrated with pinnacles of lava. Its eastern flank drops down and ends the range by merging with the outer wall. There is no sign of any continuation of the range beyond into the outer region, it being distinctly a line of peaks belonging inside of the caldera. The slopes of Neko-dake are steep, being in the main 25 to 30 degrees. A part of the summit is easily accessible, but the

highest point cannot be reached as it is an isolated monument of andesitic lava 100 feet high and having slopes of from 60 to 75 degrees on its sides.

The western flank of Neko-dake extends down most of the way to the crater floor, forming a depression in the central ridge 2,000 to 2,500 feet deep, so that the peak is left as an isolated pyramid with truncated, broken summit. The top is 4,800 feet above the level of the sea, and not much over 2,500 feet above the highest portion of the floor.

Beyond the gap just mentioned the central ridge continues westward and rises immediately into Taka-dake, the highest peak of all. It has an elevation of 5,600 feet, and rises some 4,000 feet above the plain at its base. The next peak, Naka-dake, is a somewhat lower one, on the southwest flank of Taka-dake, slightly out of line with the general east and west summit line of the ridge. Its shape is somewhat like that of a half dome, and it presents on the south side of its summit a broken precipice of black lava.

At the western base of the last two peaks the modern crater is situated, at an altitude of about 4,000 feet above the sea. The range declines still more just west of this, forming a depression in its central portion. (See left of Fig. 3 and right of Fig. 5.) This depression is by no means as low, however, as the one between Neko-dake and Taka-dake, and does not tend to break the continuity of the range as that one does. The surface of the range here is a wide upland covered with curious small steep mounds of volcanic débris.

The north and south flanks of the range sweep down with concave slopes into the wide level floor. They are furrowed by sharp ravines and intervening ridges that gradually lose their prominence among the gentler slopes toward the base. The slopes are not usually very steep, and are for the most part covered with soil and long grass. They afford little water, and are uncultivated and uninhabited.

Basaltic andesite of varying compact, cystalline and scoriaceous texture is the chief material of which the central ridge is built up. In the vicinity of the higher peaks exposures of lava are very prominent Over the lower, more gentle slopes, outcrops are infrequent. Deposits of ashes and pumice are scattered far and wide.

THE MODERN CRATER

The cone upon which the modern crater of Aso is situated has a slope of about 15 degrees and is only a couple of hundred feet high.

FIG. 7.—The modern Tuff cone on the summit of the central range, after a rain; looking northeast. The vapors issue from the northern end of the new crater. Young drainage lines are forming in the soft mud and cinders. In the foreground is a temple to the god Aso.

(See Fig. 7.) The cone is largely composed of fine-grained gray mud, which on drying becomes compacted into tuff. It is irregularly interbedded with lava and coarse fragmentary matter. This modern center of the activity of Aso is about one mile nearer the eastern than the western side of the old outer crater, but its position is roughly central with respect to the whole great oval.

The new crater is a black, ragged pit, constantly roaring and steaming. (See Figs. 8 and 9.) It has sheer walls of roughly stratified mud, the layers of which appear to dip inward, and a depth of three hundred feet or more. It is oblong in shape, and is at a rough estimate nine hundred feet across from east to west and two thousand feet long from north to south, the long axis being in the same direction as that of the outer crater. Its rim is very uneven, being much higher on the north and east than on the other sides. It is divided into five compartments or vents arranged along the long axis, each separated from the next by a steep wall of mud one hundred feet or more high. The two most northerly vents are the deepest and the only active ones. Occasionally when the vapor column diminishes one can look to the bottom of the northern vent and see the burning sulphur that plasters the lower walls and floor. The bottom is a round flat disk of cracked mud looking like the dried bottom of a pond, and there is no appearance of a hole or conduit descending to greater depths. The one next south of it is deeper and pours forth the most steam. No glimpse of its bottom could be obtained by the writer from any point upon the rim. The existence of activity in a decadent stage is indicated at other points, all in the western half of the Aso range, by jets of steam and hot springs. (See Fig. 11.)

DOUBLE RIM OF THE NEW CRATER

An interesting feature of the modern cone is a small ridge of mud that circles around the western side of the summit at a distance of about one hundred feet from the crater's edge. On climbing the cone one reaches what appears to be the summit only to find that one must descend some twenty feet into a moat and rise again a similar amount before reaching the lip of the crater. The moat acts as a line of drainage and carries the rain water southward along the summit of the cone, parallel with its long axis, to an outlet down the

mountains. On the east side there is no similar moat but the crater borders the cliffs at the foot of the peaks Taka and Naka and is separated from them by a stream channel, as shown in Fig. 10. A small double rim and moat was observed by the writer in the loose cinders for part of the way around the crater at the summit of Vesuvius in September, 1905.

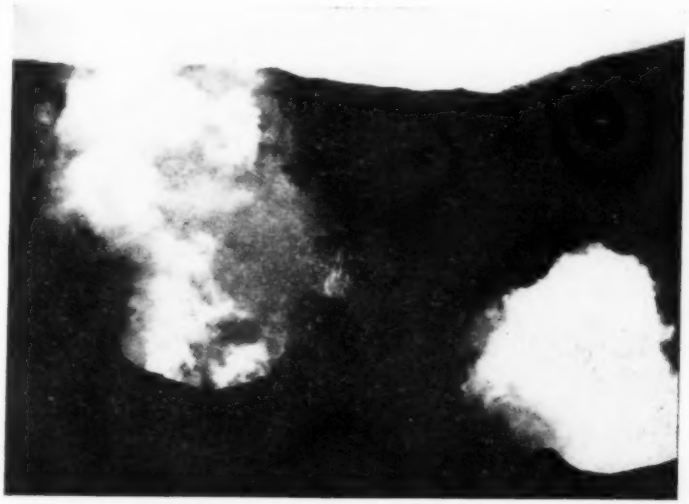

FIG. 8.—Looking northeast into the modern crater of Aso, showing the two most northerly vents and the stratified wall. These are the only active vents, the one on the right being more active and deeper. Photo by Malcolm Anderson.

HISTORY OF THE NEW CRATER

Aso-san has been in continual activity during the historical period. A detailed account of its history has been compiled by John Milne from interesting contemporaneous Japanese records.[1]

The greatest eruptions of very recent times were in the winter of 1873–74, when unusual activity continued during several months and ashes covered the ground to a distance of eighteen miles; in the winter of 1884 when ashes were blown over Kumamoto, making it so dark there at a distance of twenty-five miles that lamps had to be

[1] *Transactions of the Seismological Society of Japan*, Vol. IX, Pt. II, 1886.

used for three days; in 1889 during the year of the Kumamoto earthquake, which was the year following the great explosions of Bandai-san in central Japan; and lastly in 1894, when the floor of the modern crater was somewhat altered.

THE OUTER SLOPES

The vast open bowl of Aso occupies the summit of a great mound, the flanks of which, sloping gently away from the top of the interior wall, form a rolling hilly upland of low relief among the mountains of Kiushiu. This low dome-shaped mountain taken as a whole occupies at least 450 square miles. From above, the outer slope appears as an inclined plateau wrinkled with knolls and ridges and little valleys. All of these hillocks are of similar height, and destruction through erosion has not gone far. The general angle of slope away from the edge of the caldera is about 3 to 5°, but it is even less than this in places. On the northwest side it is very slight, because the flanks of the mound, which reach so far in other directions, there give place to a plateau between the rim and the not far distant volcanic mountains Kura-take and Ona-take. Within five to ten miles of the rim on most sides, at an elevation above the sea about the same as that of the bottom of the caldera, the outer slopes reach the foot of high mountains that almost completely encircle the upland, much as the caldera wall surrounds the plain formed by its floor. The surrounding mountain barrier is not volcanic on the east and south, where ancient sedimentary and igneous rocks form Sobo-san and other prominent peaks. The whole volcanic mass of Aso and of the mountains to the north is of the nature of a filling within a depression in the topography of the older formations.

The surface material of the outer slopes is largely fragmental débris. At a few places where it was observed exposed it appeared as massive deposits of sandy material, or as soft tuff, or as agglomerate composed of coarser fragments. Some of the hills many miles from Aso are entirely composed of fragmental volcanic deposits of this kind. Lava is frequently exposed on the western slope down to the Kumamoto plain; and in the upland region about Aso, toward the foot of the surrounding mountains, where dissection has advanced farthest, lava is much in evidence. It is most probable that

lava predominates beneath the surface throughout this whole region.

RADIATING LAVA FLOWS

Some miles to the south and east of Aso-san the surface covering of volcanic ejectamenta which has filled up and blotted out the ancient features of the landscape in this portion of Kiushiu ceases to be a solid sheet, and the underlying older formations come to light. But beyond

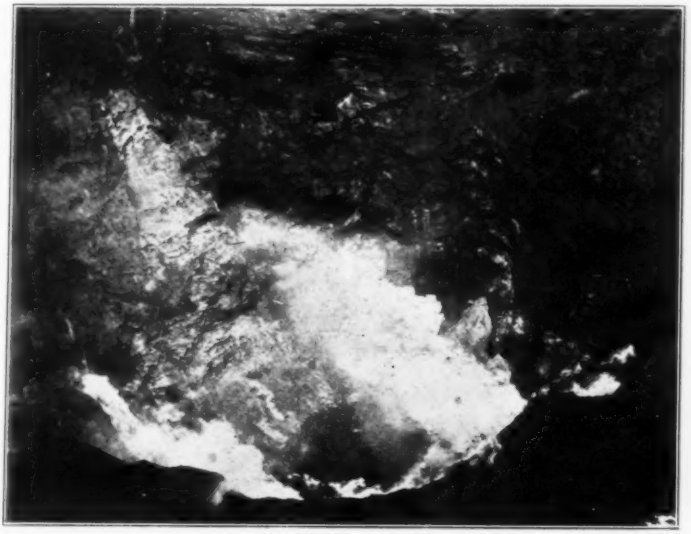

FIG. 9.—Looking down into the northernmost vent of the modern crater, showing the bottom and the sharp ridge of mud on the right between this and the next vent. The vapor comes chiefly from burning sulphur. Taken from the rim on the west side. Photo by Malcolm Anderson.

the line of contact, lava streams continue for great distances, partly burying the old river channels that radiate away from the region occupied by Aso-san, this region being the source of most of the large rivers of the island. Aso has evidently been the center of the volcanic activity of central Kiushiu and the source of supply of the erupted material mantling the region. The longest of the lava arms extends down the Gokase-gawa southeast of Aso, and was followed

by the writer to its termination on the east coast. The contact of the volcanic sheet and the older rocks in that direction is about twenty miles from the center of Aso, beyond which the lava extends down the canyon about thirty miles, almost to the sea. The width of the present lava filling of the canyon is on the average two and one-half to three miles, and the depth amounts certainly to several hundred feet. Nearly twenty-five miles away from the center of Aso the Gokase is joined by another large canyon from the north that issues from mountains in the Paleozoic formation. The lava flowed up this canyon for a distance of at least eight miles, filling its bottom likewise with a wide, deep stream. The source of the lava in this branch was the main stream that occupied the Gokase canyon. It could not have come down as a tributary flow because no volcanoes exist anywhere about.

High mountains formed of Paleozoic rocks inclose the valley of the Gokase-gawa, rising steeply above the fairly flat surface of the lava filling. In the center of this the river has cut an abrupt square canyon, and has already reached a depth of several hundred feet without coming to the level of its old course. The depth of the channel is at least three hundred feet in some places and its width is hardly more. Its sides are cliffs of basalt-andesite, usually with imperfect columnar structure. The columns, which average a foot or more in thickness, are sometimes four-sided, sometimes five-sided, the sides and angles being of irregular dimensions. They stand in the main perpendicular, but locally show deflections of a few degrees from this attitude.

CHARACTER OF THE LAVA

In the field the lava of the interior range, the ring wall and the surrounding region appeared to be the same. The rock is intermediate between andesite and basalt. That it is by no means of the most basic composition is indicated by the angle of the slopes presented in the interior range, and by the fact that explosive eruptions, with the ejection of abundant ashes and scoriae, have taken place in association with effusive eruptions throughout the history of the volcano. On the other hand, the recent-looking flows observable on the higher portion of the central range exhibit a smooth flow structure that is evidence of considerable fluidity and a prolonged state of fusion.

Three samples of lava from Aso were examined by Dr. Albert Johannsen of the U. S. Geological Survey, and the following description of these is based on the report which he kindly furnished. Specimen 1 is hypersthene-bearing basalt from the foot of the wall of the caldera near the town of Takamori on the south-east side. It is medium gray in color, compact, and highly porphyritic. The phenocrysts are about 55 to 60 per cent. labradorite, about 10 per cent.

FIG. 10.—Stream channel on the east side of the modern cone. The lip of the crater is immediately on the right, and the cliffs at the foot of the highest Aso peaks on the left. The fine gray mud is fast eroded by rains. Looking south, parallel to the long axis of the crater. Photo by Malcolm Anderson.

augite, and the rest hypersthene, magnetite, and olivine in decreasingly lesser amounts. The groundmass is made up of plagioclase, augite, and magnetite, with possibly a little glass. Specimen 2 is basalt from the same locality. It is mottled black and white, is somewhat vesicular, highly porphyritic, and strongly resembles specimen 1, especially under the microscope. The phenocrysts are about 80 per cent. labradorite, 15 per cent. augite, and the rest hornblende, magnetite, and olivine in decreasingly smaller amounts. The ground-

mass contains plagioclase, brown glass, magnetite, augite, and possibly a little olivine. Specimen 3 is a very vesicular fragment of hypersthene andesite blown from the new crater. It is composed of phenocrysts —labradorite and hypersthene in a groundmass of brown glass. Regarding these specimens Doctor Johannsen says as follows: "At best the amount of olivine in any of the rocks is slight, and with its absence I would name them all andesite."

A SUPPOSED FORMER MT. ASO

The roughly bedded strata in the walls of the big crater seem to dip away on all sides at a low angle, and their inclination is probably reflected in the gentle outer slopes that form the sides of the mound or cone of Aso. It seems likely that this mound is the basal remnant of a conical volcano that once continued upward to a culminating point high above the center of what is now the crater bowl.

If such a mountain existed it is probable that its upper portion rose with a gradually increasing slope into a summit cone. Judging from the character of the lava and the analogy afforded by the steep slopes of the present interior peaks of Aso, which seem to be constructed of materials similar to those of the wall, as well as by other volcanoes of Kiushiu (see Fig. 1), which are mostly built of similar andesitic lava and its fragmental products, the ancient cone may have risen in its upper portion even as steeply as 20° or 30°. But assuming that it rose with a constant slope no greater than now in places exhibited in the base, say 7°, its summit would have been over 7,000 feet in altitude above the sea. If it steepened above it may have been 10,000 feet or much more.

The amount of rock material that must have been removed to cause the disappearance of the whole upper portion of the cone and the opening of a wide bowl upon its site may be roughly estimated as at least fifty-four cubic miles, counting the volume of the caldera as twenty-five cubic miles—not subtracting the interior range—and the volume of the overlying cone as twenty-nine cubic miles.[1] If the cone rose steeply above, as it probably did, the volume must have been considerably more.

[1] The figures printed in the article by the writer in the *Popular Science Monthly*, Vol. LXXI, July, 1907, are incorrect.

ORIGIN OF THE CALDERA

There are three ways in which the old crater may be conceived as having originated, namely, by being built up around a vent of great magnitude, by the explosive removal of a volcanic mountain mass, or by the subsidence of the area now inclosed within the wall.

The most acceptable conclusion is that the bowl of Aso is a caldera produced by the sinking in of a volcano, as the result of the escape of

FIG. 11.—Hot springs at Yunotani near the western end of the central range. There is said to be a small geyser here that spouts out boiling water and red mud.

lava from an underlying reservoir at low points of discharge and the consequent undermining of the mountain flanks. The process was probably one of the gradual enlargement of an original summit crater.

There are three main reasons why this supposition seems to apply. In the first place, the bowl has a wide extent of almost level floor, a symmetrical oval shape, and a practically continuous ring wall of regular form. It is difficult to conceive of a violent explosion destroy-

ing the whole upper part of a mountain of such size and leaving such regular remains, whereas they might well be the outcome of a comparatively gentle process of sinking taking place simultaneously at all points around a common center. In the second place, the great lava flows radiating from the volcano are the quantitative equivalent of the mass that has disappeared from the old cone of Mount Aso, and may be reasonably considered as derived from the space in which the mountain became engulfed, having vacated this space through channels that opened at low points on the flanks of the cone. In the third place, the lava, although it is not of the most fusible variety, is of such a character that it would be capable of forming large, easily flowing and slowly cooling streams; and would not be of such viscosity as to offer the utmost resistance to explosive forces and to cause explosions of the greatest magnitude.

As regards the possibility of an explosive origin for the crater, it is to be expected that a prominent rim of débris would have accumulated around the brink of the cavity had such an immense block of the earth's surface been removed in this manner. Although it is true that a vast amount of fragmental material is present in the wide region surrounding Aso-san, no such rim is to be found. The balance of probability favors the conclusion that upward discharges of material did not play a chief part in excavating the bowl, but that the masses of ejectmenta covering much of the region around the volcano were thrown out partly before the destruction of the ancient mountain and partly during the period in which the process of engulfment was progressing, as a secondary phenomenon attending that catastrophe. The strata in the wall tell of explosive eruptions that took place contemporaneously with the emission of lava streams in the early history of the volcano, but it appears that the erupted material was chiefly in the form of lava flows. On the other hand, the decadent stages of the volcano have been marked chiefly by explosive eruptions as witnessed by the new cone and the deposits in its vicinity, and by the historical accounts.

As regards the other hypothetical mode of origin, the low cone of Aso may be thought of as having been formed by a process of cone building, through the overflowing of lava from a very large vent and the accumulation round about of material explosively removed.

But it is scarcely conceivable that a process alone of building up could have produced such forms as those of Aso.

John Milne discusses the origin of the Aso crater in the account of his visit to it before mentioned.[1] He considers unfavorably the theory of an explosive origin and comes to the following conclusion:

> I should be inclined to look upon it as being now, as it ever was, the upper crater of an old volcano, inside which in more recent times a cone has grown. Although at the commencement of the mountain the action may have been cataclysmic in its nature, subsequently, however, I should think that it grew up higher, partly by the accumulation of ashes, but now perhaps by the boiling over of a highly liquid trachytic lava. That this latter action has taken place seems to be testified by the roughly stratified appearances which are exhibited in the ring walls; the growth has in fact been probably something like the growth of Mauna Loa in the Sandwich Islands or as a geyser tube in Iceland.

ORIGIN OF THE CENTRAL RANGE

The theory of a subsequent origin for the interior range is the only acceptable one. The caldera may have originated over the intersection of 2 fissures, one running north and south parallel to the long axis of Kiushiu determining the long axis, and one at right angles determining the shorter axis and affording a line of activity along which a ridge of cones was later built.

ORIGIN OF THE BARRANCO

The single opening in the wall has been described as immediately opposite the western end of the central range. It may be that its origin is due to the line of weakness supposed to exist along the diameter occupied by this range, and that it was contemporaneous in origin with the caldera. Or it is possible that forces aided in the destruction of this point in the wall at the time that great eruptions were taking place along the central line and the new range was being built.

Another supposition is that it is a truncated canyon of the former Mount Aso, which has cut back and tapped the floor since the caldera was formed. There is not much evidence that the flanks of the former Mount Aso had become deeply dissected during the interval between its construction and its disappearance, and there is no other canyon making a comparably deep gap in the wall. Therefore the outlet

[1] *Popular Science Review*, New Series, Vol. IV, No. 16, October, 1880.

of the streams owes its origin more probably to one of the first-mentioned causes, or to the aid afforded by structural weakness to erosional work.

LIST OF LARGE CRATERS

A review of the literature on volcanoes reveals the fact that there are very many craters and volcanic depressions comparable with the Aso caldera in form and origin. The frequency of occurrence and importance of this type has not received adequate recognition in most of the textbooks. The following list gives the dimensions of some of the largest known craters, and of a few smaller ones that are typical calderas, out of the hundreds of large craters that might be cited. It is probable that the majority of these mentioned are volcanic sinks—have resulted, that is, from the subsidence of portions of volcanic mountains—and may therefore be termed calderas.

Monte Albano, in Italy, has a ring wall inclosing a crater 7 by 6 miles in dimensions.

Lago di Bolsena and Lago di Bracciano are crater lakes in Italy, the former measuring 8.5 by 7.5 miles, and the latter being round and with a diameter of 5.5 miles.

On Vesuvius, the old crater of Somma must have been nearly circular and 3 miles in diameter.

Val del Bove, on Mt. Aetna in Sicily, is a caldera 4 or 5 miles in diameter.[1]

Pantellaria, between Sicily and Africa, has traces of a crater ring 12 miles in diameter.[2]

Santorin, in the Mediterranean, is a volcanic ring 18 miles in circumference.

Palandökan, in Armenia, has a crater with long axis of 6 miles.[3]

Dyngufjöll, in Iceland, has a crater about 8 by 4 miles in dimensions with an area of 25 square miles.[4]

[1] Charles Lyell, *Principles of Geology*, 10th ed., Vol. I, p. 630.

[2] G. Poulett Scrope, *Volcanos*, 1872, p. 429.

[3] Hermann Abich, *Geol. Forschungen in den kaukasischen Ländern*, Theil II, Vienna, A. Hölder, 1878–87.

[4] Th. Thoroddsen, *Geog. Journ.* (London), Vol. XIII, Nos. 3 and 5, March and May, 1899.

Palma, in the Canary Islands, has a crater that has been reported as 9 miles in diameter.[1]

Teneriffe, in the same group, has a crater with longest diameter of 8 miles.[1]

St. Helena Island preserves the wreck of a crater which according to Darwin[2] may have measured 8 or 9 by 4 miles. From other descriptions the longest diameter does not appear to have been more than 4 or 5 miles.[3]

Mauritius according to Darwin has remnants of an oval crateral ring with shorter diameter of 13 miles.[2 and 4]

San Thiago (St. Jago) Island has a remnant resembling in character and size that of Mauritius.[2]

Réunion has a central, crater-like depression that is approximately round and 6 miles in diameter.[5]

Antandroy, in Madagascar, has a partially destroyed crater with diameter of 15 miles.[6]

In the District of Ngorongo, in East Africa, an apparently crateral depression measuring over 12 miles across has recently been described.[7]

Kamtschatka is said to contain a crateriform lake 15 miles in diameter surrounded by the Palan Mountains, and another large lake, called Kranosk, probably crateral.

Japanese lakes.—The following lakes of northern Japan may occupy calderas:

Tazawa, about 60 miles west of Morioka, Hondo. It is 6 miles in diameter, and the volcano Komago-take is within 10 miles of it.

[1] Leopold von Buch, *Physikalische Beschreibung der canarischen Inseln*, Berlin, 1825; also, *Ges. Schriften*, herausgeg. von Ewald, Roth und Dames, Vol. III, 1877, p. 150.

[2] Charles Darwin, *Geological Observations on Volcanic Islands*, London, Smith, Elder & Co., 1851, pp. 29–30.

[3] J. C. Meliss, *St. Helena*, London, L. Reeve & Co., 1875.

[4] M. Bailly, *Voyage aux Terres Australes*, tome I, p. 54.

[5] Charles Vélain, *Description Géologique de l'Ile de la Réunion, etc.*, Paris, Typographie A. Hennuyer, 1878.

[6] E. F. Gautier, *Madagascar*, Paris, Libraire Maritime et Coloniale, 1902.

[7] Fritz Jaeger, *Mitteilungen aus den deutschen Schutzgebieten*, Nos. 2 & 3, 1907. See also a review of this in the *Geog. Journ.* (London), Vol. XXX, 5, November, 1907, p. 560.

Towada, about 60 miles south of Aomori, Hondo. It is 10 miles in diameter and irregular.

Toya, near the coast north of Volcano Bay in Hokkaido. It is round and over 10 miles broad, and contains two islands. The volcano Usu-dake rises just south of it.

Shikots, over 60 miles south of Sapporo, Hokkaido. It is an irregular lake nearly 14 miles long and 7 broad surrounded by high mountains. There are volcanoes within 5 miles both northwest and southeast of it.

Kutcharo, over 50 miles south of the southernmost part of the north coast, in the northeast corner of Hokkaido. It is irregular, with approximate dimensions of 15 by 8 miles, and surrounded by mountains. A volcano and hot spring are just east of it.

Bombom, Luzon, is a rudely oval crater lake with mean diameter of 12 miles.[1]

Java[2] contains the following large craters: Ringguit, a remnant of a ring that may have had a diameter of 13 miles; Idien, a remnant with possible diameter of 10 miles; Hiiang, faint traces of an outer crater of 10 miles diameter; Tengguer, an entire summit crater over 5 miles across; there are also 3 other adjoining craters, and the 4 together seem to form a single elliptical depression measuring 7 by 5 miles; Ngadipouro, a remnant of a ring 6.5 in diameter; Tounggoul and related craters, 3 large rings that together seem to form a depression 15 miles long, and 12 miles wide at one end and 4 miles at the other; Danou, one remnant indicates a formerly existent ring 9 miles across, and 3 other rings together seem to form a crateral inclosure measuring 8 miles by 3; Prinsen-eiland between Java and Sumatra forms a partial ring 6.5 miles across; and the 4 islands of Parang, north of Java, make up a possibly crateral ring with diameter of 6 miles.

Maniendjoe and Singkarah are 2 lakes in Sumatra that probably

[1] Richard von Drasche, *Fragmente zu einer Geologie der Insel Luzon*, Vienna, Verlag von Karl Gerold's Sohn, 1878. Also, G. F. Becker, *Twenty-first Ann. Rept.*, U. S. Geol. Survey, 1899–1900, Pt. III.

[2] Franz Junghuhn, *Java;* German translation, Leipzig, Arnoldische Buchhandlung, 1857. Also, Verbeek and Fennema, *Description géologique de Java et Madoura*, Amsterdam, Joh. G. Stemler, 1896.

occupy crater basins; the greatest dimensions of the former are 14.5 by 7 miles, and of the latter 13 by 4.5 miles.[1]

Deception Island, in the South Shetland group, contains an oval crateriform harbor 6 miles long and 4 miles wide.

The well-known craters of the Hawaiian Islands are representative of the caldera type. The largest of them is Haleakala, which is of irregular shape and covers 16 square miles. It has 2 arms, each of which is about 6 miles long and 2 miles wide.[2] Mohokea caldera on the side of Mauna Loa measures about 6 by 5 miles.[3]

In Galapagos Islands there are 5 large craters on Albemarle Island. The largest is at the south end and has a length of about 12 and a width of about 6 miles. The others vary in size down to a length of 3 miles or less.[4]

The Central American lakes,[5] Atitlan and Amatitlan in Guatemala, and Ilopango in San Salvador, are 3 lakes whose origin was probably due to volcanic subsidence, although there is a difference of opinion regarding them. The first is 12.5 by 9 miles in greatest dimensions, the second, 9.5 by 3.5, and the third, 12.5 by 5 miles.

Masaya-Nindiri volcano, in Nicaragua, is surrounded by the remains of a crater that must have had a long diameter of 5 or 6 miles.[5, 6]

Crater Lake, in Oregon, occupies a deep caldera measuring 6 or more by 4.5 miles and having an area of 20.5 square miles.[7]

[1] R. D. M. Verbeek, *Topographische en Geologische Beschrijing Sumatra's Westkust*, Batavia, Landsdrukkerij, 1883.

[2] J. D. Dana, *Characteristics of Volcanoes*, New York, Dodd, Mead & Co., 1890. Also, Clarence Dutton, *Hawaiian Volcanoes*, Extract from 4th Ann. Rept., U. S. Geol. Survey, 1882–83, pp. 126–28.

[3] C. H. Hitchcock, *Bull. Geol. Soc. Am.*, Vol. CXII, October, 1906, pp. 485–96.

[4] This information was kindly furnished by Mr. W. H. Ochsner, of Stanford University and the California Academy of Sciences, who recently returned from a geological trip to these islands.

[5] E. G. Squier, *The States of Central America, etc.*, New York, Harper & Bros., 1858. Also, A. Dollfuss and E. de Montserrat, *Voyage géologique dans les républiques de Guatemala et de Salvador*, Paris, Imprimerie Impériale, 1868.

[6] Karl von Seebach, *Ueber Vulkane Centralamerikas;* aus den 38sten Bande der *Abhandlungen der Königlichen Gesellschaft der Wissenschaften zu Göttingen*, Dieterichsche Verlags-Buchhandlung, 1892.

[7] J. S. Diller, *Professional Paper, No. 3*, U. S. Geol. Survey, 1902.

SUMMARY

The caldera of Aso is a great depression at the summit of a low mound-shaped cone in the center of the island Kiushiu, within 22 to 35 miles of the sea and only 1,000 to 3,000 feet above it. It has been the center of vast outpourings of lava and fragmental material that have filled a depressed area in the topography of the older formations during Quaternary time. It is one of the largest, if not the largest, of craters known on the earth.

The caldera has been worn considerably, but the wall has not been removed by erosion at any point, the single barranco being considered as due chiefly to structural weakness or subsequent disruption. The floor has been built up as well as worn down and probably retains fairly well its original level. The caldera appears to date from about middle Quaternary time.

In the history of the volcano both effusive and explosive eruptions have been characteristic, and have occurred contemporaneously, the amount of material emitted as lava flows having probably been greater.

The lava is intermediate between andesite and basalt, and is of comparatively easy fusibility.

There existed formerly a volcanic cone above the site of the present caldera, of which the truncated base is preserved in the outer slopes. The caldera grew as a result of the discharge of great lava flows and the collapse of this cone. The process was probably one of gradual enlargement of a summit crater.

A high, continuous interior range was later built up by eruptions along a fissure at right angles to the long axis of the caldera; and the cone building still continues, though with diminishing vigor, in a modern crater centrally situated with respect to the old one.

MARGINAL GLACIAL DRAINAGE FEATURES IN THE FINGER LAKE REGION[1]

JOHN L. RICH
Cornell University, Ithaca, N. Y.

A study of a considerable number of the channels or scourways formed by streams associated with the Pleistocene ice sheet in the southern Finger Lake region of New York has served to bring out many features of more than local interest and importance, both as to the broader phases of glaciation in this part of New York State, and as to the value of a study of such channels as an aid in working out the glacial geology of a region.

This study has a distinct bearing on the interglacial problem in that several of these channels give conclusive evidence of more than one stage of glaciation, while one points strongly to three or more such stages with corresponding interglacial epochs, some of which seem to have been considerably longer than post-glacial time. Other channels are so situated as to make possible a fairly accurate estimate of the slope of the ice margin along the valley tongues. Still another furnishes proof of an extensive sinking of the surface consequent upon the melting-out of a large block of buried ice—a phenomenon, the importance of which seems not to be fully appreciated.

The Finger Lake region, lying as it does along the belt of the great recessional moraines of the Wisconsin ice sheet, is especially favorable for the study of marginal glacial drainage features. The long halts of the glacier, while the moraines were building, gave ample time for the associated streams to carve for themselves distinct channels which, now that the ice is gone, are in most cases left dry and entirely out of harmony with the present drainage.

[1] This paper is an abstract of a thesis presented to the faculty of Cornell University in June, 1907, as a requirement for a major in Physiography. The work was undertaken at the suggestion of Professor R. S. Tarr, to whom the writer is indebted for helpful suggestions, and for the location of many of the channels herein described. In the course of folio work for the U. S. Geological Survey, Professor Tarr discovered several of these channels, some of which are described in his report soon to be published by the Geological Survey.

CHANNEL TYPES

The glacial channels of the Finger Lake region are of several different types, representing various conditions of formation, ranging from small streams at the ice margin to the outlet streams of large glacial lakes. It has been found desirable in describing these channels to classify them into five groups, based on the most common conditions of formation. The following five types have been selected:

I. *Marginal.*—Channels formed by streams flowing close along the ice margin.

II. *Submarginal.*—Channels of a broadly marginal nature; not, however, following closely the edge of the ice; cutting across hill spurs or behind small outlying hills.

III. *Lateral.*—Channels formed by streams leaving the glacier through a notch in the bordering hills and flowing laterally away from the ice.

IV. *Morainic channels.*—Channels formed while a moraine is building by contemporaneous streams issuing from the ice. Often indistinct; best developed in flat moraine near the end of an ice-lobe.

V. *Glacial lake outlets.*—Channels formed by the outlet streams of glacier-dammed lakes.

It must be borne in mind that it is often difficult, if not impossible, to draw sharp lines of distinction in all cases. This is necessarily so because of the variations in conditions under which the channels were formed.

In this paper only selected examples of each type are described. In so far as possible channels have been selected which illustrate well the type, and at the same time show features of more than local interest.

TYPE I. MARGINAL

Slaterville channels.—One of the most typical channels of the marginal type is found about two miles east-northeast of Slaterville Springs (Dryden sheet, U.S.G.S.) on the east side of Six Mile Creek valley at an elevation of about 1,640 feet near the top of the southmost hill. The channel starts as a slight trimming of the hill slope. This increases gradually until at first a flat bench, and later a two-sided channel is cut in the slope (Fig. 1). The channel bottom has a width of about one hundred feet and is very flat and swampy. A profusion

of trunks and branches of hemlock trees is scattered over the bottom; a rather characteristic feature of such channels in this region. The lower bank, or the one which was nearest the ice, is low, varying from two to ten feet in height. The opposite bank, formed by trimming of the hillside, is very steep, and thirty or forty feet high in places. The

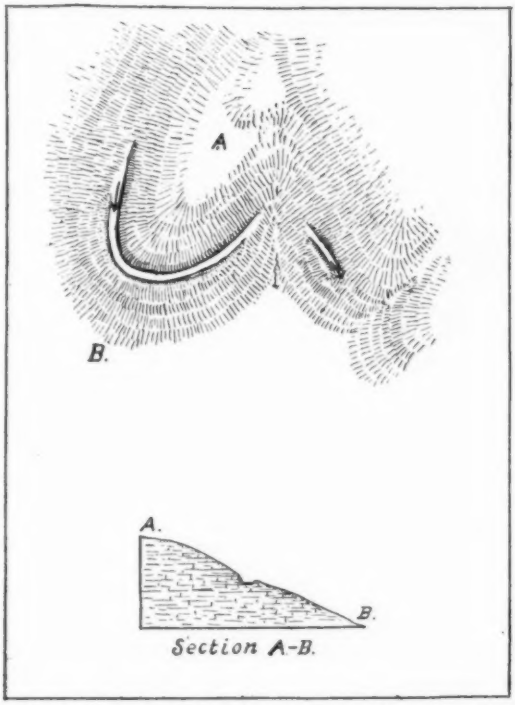

FIG. 1.—Sketch of Slaterville Springs channel, showing its contour-like character.

channel, beginning on the west side of the hill, follows closely the contours around the south end to the east side, where it becomes lost for a short distance as it crosses a small valley or gully, but reappears again, though less distinctly, beyond.

An interesting feature is the disappearance of the channel in crossing the small valley, and its re-appearance on the opposite side. It may be that a block of stagnant ice, probably more or less buried, lay

in the valley and formed the stream bottom. If such were the case we would expect to find no distinct channel after the ice had melted.

At an elevation two hundred feet lower on the same hill, and almost due southwest of the channel just described is another of the same general type. It begins on the west slope of the hill as a shallow, indistinct, slightly swampy channel with banks varying in height from one to three feet. After continuing thus for about 150 feet it suddenly changes, at the site of an ancient waterfall, to a deep partly rock-sided gorge which contours the hill for a distance of about one-fourth mile. Its depth here is approximately forty feet. A short distance east of the mouth of this channel is another shorter one cut in the rock at the base of the hill. The two were probably contemporaneously formed by the same stream.

Several features of this channel show that it was formed previous to, or during the *advance* of the last ice-sheet, and that streams associated with the *retreating* Wisconsin ice did little more than to clear out a part of the débris with which the channel had been filled. The lines of evidence pointing to this are: (1) the present V-shape of the gorge, (2) the presence of considerable drift within the gorge, and (3) the only occasional outcrop of rock in the gorge walls. The bottom is not flat as would be expected if the gorge had been cut by the last stream which flowed through it. The flat portion of the bottom is very narrow; only a fraction of the width of the gorge, and in no part of the bottom is rock visible.

This is one of two channels among the large number studied, in which the sites of waterfalls were found.

Wedgwood channel.—One and one-half miles west-southwest of Wedgwood Station (No. 1, Fig. 2, from Watkins sheet, U. S. G. S.) is a marginal channel distinctly older than the final retreat of the last ice-sheet. It is now largely drift-filled and shows no trace of the presence of a stream since it was uncovered by the ice. It is not flat bottomed, as are the undisturbed channels, but has a decided V-shape. East of the channel a small rock hill has been isolated by the channel cutting. Rock is exposed in the walls in only a few places. One exposure at *X* (Fig. 3) shows an approximately vertical rock wall buried beneath the glacial drift which partially fills the gorge. A few feet north of *X* the channel bottom rises several feet to a drift divide

which is distinctly *within* the main channel, but shows no trace of stream action. Beyond the divide a hummocky deposit continues nearly to the small stream which here crosses nearly at right angles to the direction of the channel. In this stream, approximately in line with the west channel wall, is a waterfall probably formed by the

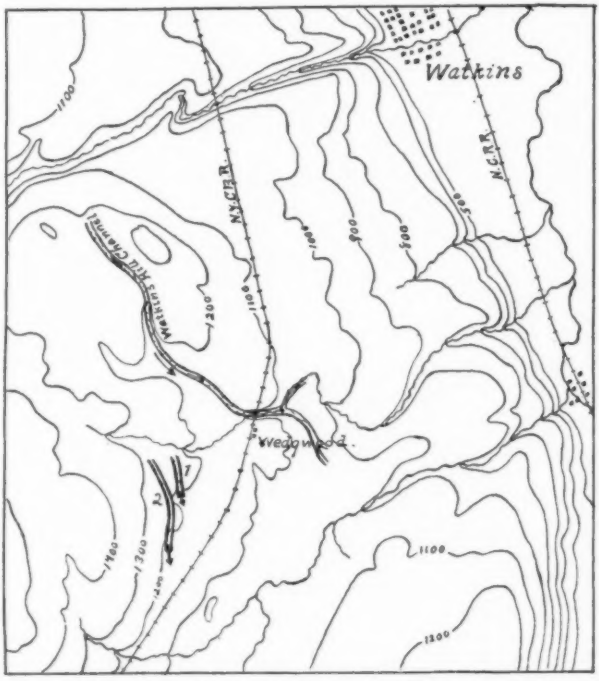

FIG. 2.—Wedgwood and Watkins Hill channels. These channels were formed at the margin of an ice-lobe moving southward through the Seneca Lake valley shown on the eastern side of the map. Scale 1/62,500.

present stream encountering the rock wall of the buried gorge. A short distance below the fall the conditions shown in *A–B* (Fig. 3) may be seen. There is a rock terrace about thirty feet wide at a level three feet above the present stream. The stream, however, is not flowing on rock. It seems to have discovered a buried channel, for both its bottom and its southwestern side are composed of drift.

This condition of the stream, together with the occurrence of the falls a short distance above and the rocks walls at *X*, indicates the presence of a buried gorge extending at least as far north as the stream, beyond which, if present, it is entirely concealed by drift.

Only a few hundred feet west of the channel just described, and a

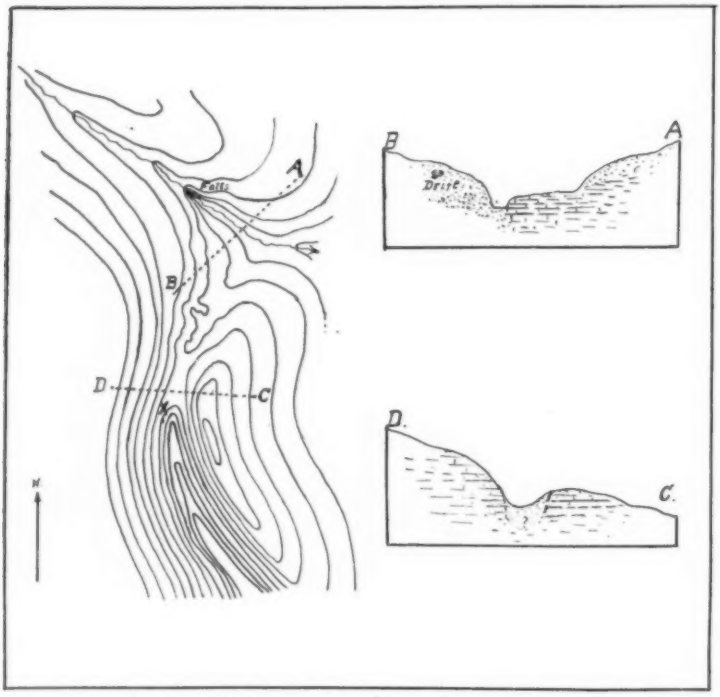

FIG. 3.—Sketch of Wedgwood channel (1). Scale of contour sketch about six hundred feet to the inch. The profiles are slightly exaggerated to bring out essential features.

little further up on the hillside (2, Fig. 2) is another of a strictly marginal type which follows for over one-half mile along the hill. There is here distinctly a channel within a channel; the smaller and later one formed during the final retreat of the ice; the other at an earlier date. The older channel is partially drift-filled, yet maintains distinct banks throughout most of its course. The banks are not

sharply trimmed. In the lower end are several hummocks, apparently of a morainic nature. This older channel was occupied during the retreat of the last ice-sheet by a small stream which formed a second channel twenty or thirty feet wide within the older one, which has a width of about 125 feet. The smaller channel has distinctly trimmed though low banks, and a characteristically swampy bottom. At its upper end the older channel is buried in a gently undulating moraine in which the smaller and later stream seems to have originated.

TYPE II. SUBMARGINAL

Cayuta Gorge channel.—An excellent example of this type is Cayuta Gorge at the outlet of Cayuta Lake (Fig. 4; Ithaca sheet, U. S. G. S.). The lake lies in a broad, mature valley trending a little south of southwest. At its southern end a glacial deposit, about forty feet in average height stretching across the valley, forms the dam to which the lake owes its origin. In one place on the west side of the valley near the schoolhouse the top of this barrier is less than twenty feet, and probably not more than ten feet above lake level. Through this gap to the south is free communication with Catlin Mill Creek, and thence with Seneca valley; yet the lake waters, instead of finding an outlet through this low pass, turn eastward and escape through a rock gorge cut to a depth of over three hundred feet through the hill bordering Cayuta valley on the east (Fig. 4). That this outlet is no normal valley, is shown by its almost perpendicular rock sides and its lack of harmony with the surrounding topography. Clearly nothing but the intervention of a glacier could have produced such an abnormal drainage condition in a region of horizontal and comparatively homogeneous rocks.

As is show by a map of the moraines of this region,[1] a lobe of ice from the great Seneca valley tongue lay for a long time across the lower end of Cayuta Lake valley. Such an ice-lobe would obstruct the normal drainage and cause the water to escape over the lowest point in the valley side. This, in this case, clearly must have been the site of the present gorge. In order to permit the cutting of so profound a gorge, the glacier must have stood nearly stationary for a long time. It might have been melting away as fast as the gorge was being cut

[1] Tarr, *Bul. Geol. Soc. Am.*, Vol. XVI, 1905, pp. 215–28.

down, but no faster, for if melting were more rapid than downcutting, a new channel farther down the hillside would at once be begun.

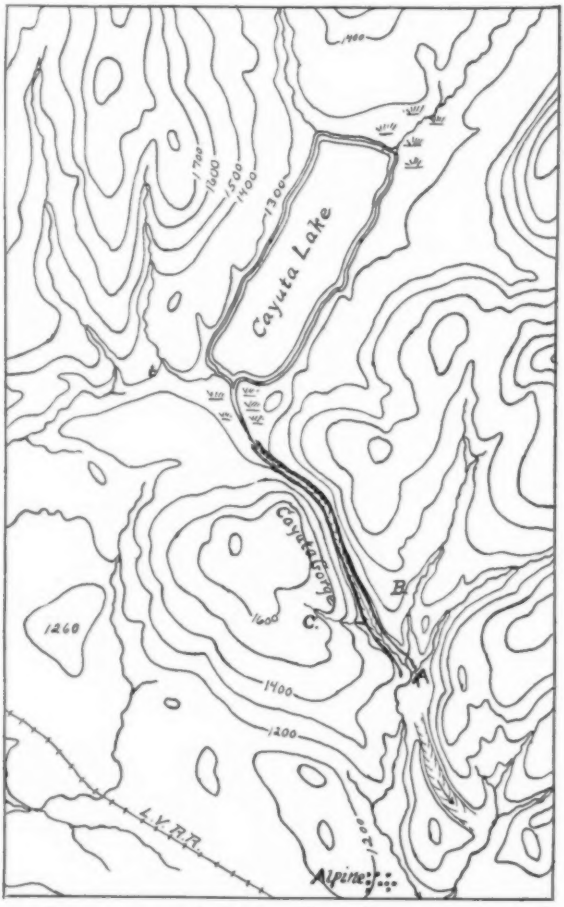

FIG. 4.—Cayuta Gorge and vicinity. Note tributary streams *A*, *B*, and *C*, referred to in the text. Scale 1/62,500.

A channel of this type could be formed only in connection with a *retreating* or possibly stationary phase of ice-movement; never in connection with an advancing movement, for, since the initial stage

of such a channel begins high up on the hill, if after the channel had been started the ice continued to advance, the channel would soon be covered and another farther up the hill slope would be begun. Such reasoning strongly supports the belief that this channel was formed by waters associated with a retreating ice-sheet. It was not, however, formed during the final retreat of the last ice, for within the gorge itself are deposits of glacial drift which the stream is still engaged in removing. It has nowhere as yet reached rock bottom. The presence of the drift clearly proves that, after the gorge had been cut to a depth greater than the present, it was subjected to glacial action.

The cutting of the gorge has introduced a hanging condition in the streams *A*, *B*, and *C* (Fig. 4). The stream *C*, which, as the map shows, has only a small drainage area, enters Cayuta Gorge without falls through a drift-filled rock gorge thirty or forty feet in width. The stream bottom, at least in the lower part of the gorge, is entirely on drift. The presence of this drift-filled tributary gorge shows that, since the glacial epoch during which Cayuta Gorge was formed, there came an erosion interval long enough for a small stream to cut a good-sized rock gorge. After this period of erosion came another epoch of glaciation during which the gorges were filled with drift. Since glacial times this stream, working over a very steep grade, has been unable to remove the drift from the gorge which in the interglacial interval it had cut in solid rock. This would indicate that the ratio of interglacial to postglacial time is roughly that of the time taken by a stream to cut a gorge in rock to that taken by the same stream to cut a gorge of about equal size in drift.

Stream *B* shows an even more complex history. It enters Cayuta Gorge at a rather steep grade through a gorge which is distinctly interglacial in character. Its walls are veneered with drift and appear much weathered. The stream, which flows in a series of cascades over a rock bottom seems to have deepened its channel in the rock by about six feet since glacial times. One-fifth of a mile above its mouth the gorge widens out into a nearly circular amphitheater (Fig. 5) at which there is an abrupt change in direction and an absolute change in the character of the gorge. For one-half mile or more above the amphitheater the stream flows with an even grade through a rock-walled, partly drift-filled gorge at least three times wider than

that below. The gorge bottom in this upper part is about 120 feet wide and shows rock in only one or two places, then not sufficiently to cause falls or rapids. The walls show marked decay. In line with this upper gorge and running from the amphitheater to the side of Cayuta Gorge is a sag of about fifteen feet in the surface which undoubtedly marks the drift-filled continuation of the gorge above (see Fig. 5).

The Stream *B*, then, above the amphitheater, is flowing in a gorge distinctly broader and older than the interglacial one which it follows from the amphitheater to its junction with Cayuta Gorge. If this larger gorge is due to a hanging condition initiated by the cutting of Cayuta Gorge then, in order to explain the facts, appeal must be made to three periods of glaciation; for what but the intervention of a glacier would account for the diversion of the stream from its broader gorge to the one, itself interglacial, which it occupies in the lower part of its course? It has been suggested however, that the older gorge may be the result of a regional rejuvenation antedating the appearance of the first ice-sheet. Such a rejuvenation, evidence of which has been found by Tarr in many of the streams of this region, might account for the conditions here found without appeal to more than two periods of glaciation.

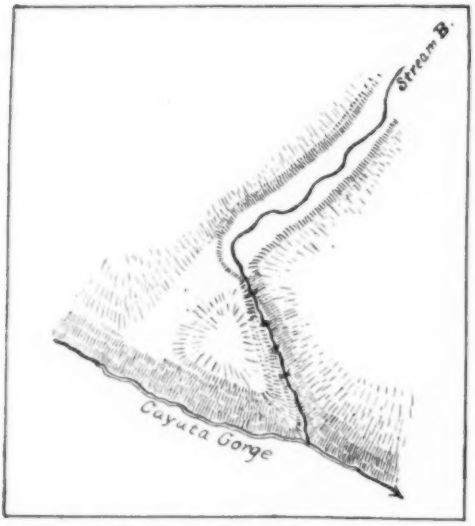

FIG. 5.—Sketch of tributary Stream B. Note the broad upper gorge, and the narrower one, itself interglacial, through which the stream reaches Cayuta Gorge.

It seems probable, however, if Stream *B* cut a gorge due to regional

rejuvenation that it was tributary to the neighboring Stream *A* rather than to Cayuta Gorge. This belief is based on the fact that the drift-filled gorge at the mouth of *B* appears to be hanging well above the present stream in Cayuta Gorge, and that in *A*, about one-third of a mile above its mouth, there is a break in the continuity of the rock wall on the west side, above which the gorge is decidedly narrower; a condition which suggests strongly the entrance of a large tributary gorge from the west.

For these reasons, though one gorge may be due to rejuvenation, it is believed that the others represent at least three ice invasions with corresponding intervals of deglaciation.

Evidence as to the interglacial nature of these gorges is of considerable importance, owing to the fact that while the multiplicity of glacial epochs has been proven in many parts of the United States, it has not been fully recognized for this region. As late as 1905 we have the following statement from Fairchild[1]: "It is safe to discuss the history of the region as involving only the Wisconsin glacial epoch, for no evidences of any earlier and more forceful and extended ice sheet have been found." Previous to 1906, Tarr[2] held that there was no direct evidence of more than the Wisconsin ice invasion. In that year, however, he published evidence based on the buried gorges which led him to the conclusion that there have been at least two epochs of glaciation.[3] Maston[4] in 1904 described a series of buried gorges in Buttermilk valley near Ithaca which led him to the belief that at least two and perhaps four ice-sheets had invaded this region.

TYPE III. LATERAL

Spencer Summit channel.—A typical lateral channel is found one and one-half miles east of the Lehigh Valley railway station at Spencer Summit, a short distance south of the Thompkins County line and one-fourth mile east of Michigan Creek (Dryden sheet, U.S.G.S., Fig. 6). Beginning just beyond the divide in the deep notch through which the road passes, it follows a southeasterly course along the preglacial valley heading near the notch. For the

[1] *Bul. Geol. Soc. Amer.*, Vol. XVI, p. 67.

[2] *Ibid.*, pp. 217, 237–42.

[3] *Jour. Geol.*, Vol. XIV, 1906, pp. 18–21.

[4] *Ibid.*, pp. 133–51

first mile of its course the channel is very distinct, flat bottomed and from 100 to 150 feet in width. Farther down it is less distinct owing to the entrance of tributary valleys whose streams have modified the old channel bottom.

Contrary to what would be expected, the channel does not begin at the divide. Here the notch is V-shaped in cross-section, and at the bottom scarcely wider than the highway. Rock is visible in the walls, but there is a considerable drift filling. About two hundred feet

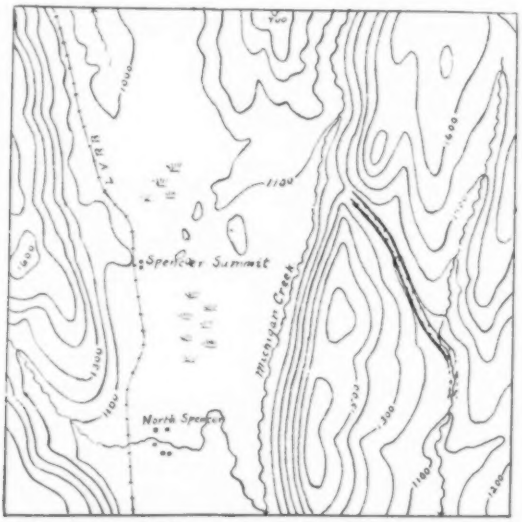

FIG. 6.—Spencer Summit channel. A typical lateral channel. The ice-tongue moved southward through the deep, steep-walled valley in which Spencer Summit is situated. Scale 1/62,500.

east of the divide the channel begins suddenly. It is very swampy and attains almost its full width at the very beginning.

A probable explanation of the absence of the channel at the divide is that a small ice-lobe from the main Cayuga valley tongue pushed partly through the notch, and from its terminus discharged the stream which formed the channel. This is a condition almost exactly similar to that found by Tarr at Floral Pass, along the eastern border of Hayden Glacier, Alaska.

Johnson Hollow channel.—Two and one-half miles north of the town of Millport, and an equal distance east-southeast of Moreland is the beginning of another interesting lateral channel. It was formed by a stream from a small lateral lobe which pushed from the great Seneca valley ice-tongue for a short distance through the gap in the hills on the west side of the valley. The stream flowed for a little over a mile in a northeasterly direction, almost opposite to that of the ice-motion in the adjacent valley. It then turned and flowed a little south of west for another mile, then southward through Johnson Hollow and finally back to the ice three miles below the starting point. (See Fig. 9.)

This channel, like those already described, has a flat, swampy bottom and distinctly trimmed banks. For the first mile of its course its width varies from 100 to 150 feet. The elevation at the beginning is 1,200 feet, and at the foot of Johnson Hollow, where it again reached the ice tongue, 1,000 feet. This gives a drop of two hundred feet in a distance of three miles, or an ice-slope of sixty-six feet per mile.

At the head of Johnson Hollow is a series of several channels of which this is one. The entire series will be fully described on a later page with special reference to the relation of the various channels to each other and to the ice-front.

Watkins Hill channel.—Beginning on the west side of Watkins Hill (Fig. 2, Watkins Sheet, U. S. G. S.) is another lateral channel which after a course of about two and one-fourth miles, again reached the ice-tongue, against which it built a distinct gravel plain. The difference in elevation of the two ends of this channel is approximately 150 feet. This, in two and one-fourth miles, gives an ice slope of sixty-seven feet per mile; practically the same as that determined for the Johnson Hollow channel.

Remarks.—The condition favorable for the formation of a lateral channel is the presence of an ice-tongue lying in a valley bordered by hills. Under these conditions the marginal drainage is apt to be diverted by any low gap in the valley sides, giving rise to a lateral channel. It often happens that a stream after thus leaving the ice finds itself in a valley tributary to that in which the ice-tongue lies. It will then, after a longer or shorter course, return to the main

valley. If it finds this still occupied by the ice, a marginal deposit, either a gravel plain or a delta, will be formed. Which of the latter is formed will depend on whether or not a marginal lake is held up in the tributary valley. When such a deposit is preserved the two points, one where the stream leaves the ice, and the other where it again reaches it, furnish valuable data as to the position and slope of the glacier tongue at the time the deposits were forming.

TYPE IV. MORAINIC CHANNELS

None of the morainic channels studied show features worthy of separate description. A short summary of the most characteristic features of such channels is therefore given instead of detailed descriptions of individual channels.

Morainic channels as seen in the region of the Finger Lakes are characteristically weakly developed. They are often short, irregular, and marked in many cases by scarcely more than a modification of the drift into flat, stream-bottom form. Such a condition is what should be expected. The ice while a moraine is building is subject to more or less backward and forward oscillation. Temporary streams are developed here and there, and under most conditions the great amount of morainic débris supplied to these streams causes them to aggrade rather than to degrade; to build up the channel bottom rather than to cut it deeper. Hence the prevalence of broad, flat-bottomed channels with ill-defined banks.

TYPE V. GLACIAL LAKE OUTLETS

Watkins Lake outlet.[1]—The outlet of Lake Watkins, held up by the glacier in Seneca valley, has already been described in part by Fairchild[2] and later by Watson.[3] Both, however, failed to see and describe the most interesting part of the channel—its beginning and the first one and one-half miles of its course. Both described the channel as beginning at Pine Valley (Fig. 7; Elmira sheet, U. S. G. S.) and continuing southward past Horseheads to the Chemung River at Elmira. Pine Valley was considered the site of the lake outlet as is shown by the following from Watson:[4] "This channel has an equally

[1] In connection with his folio work, Tarr first discovered the part of this channel above Pine Valley.

[2] *Bul. Geol. Soc. Am.*, Vol. VI, 1894–95, pp. 365–68.

[3] *N. Y. State Museum Rept.*, Vol. LI, 1897, p. 74.

[4] *Loc. cit.*, p. 74.

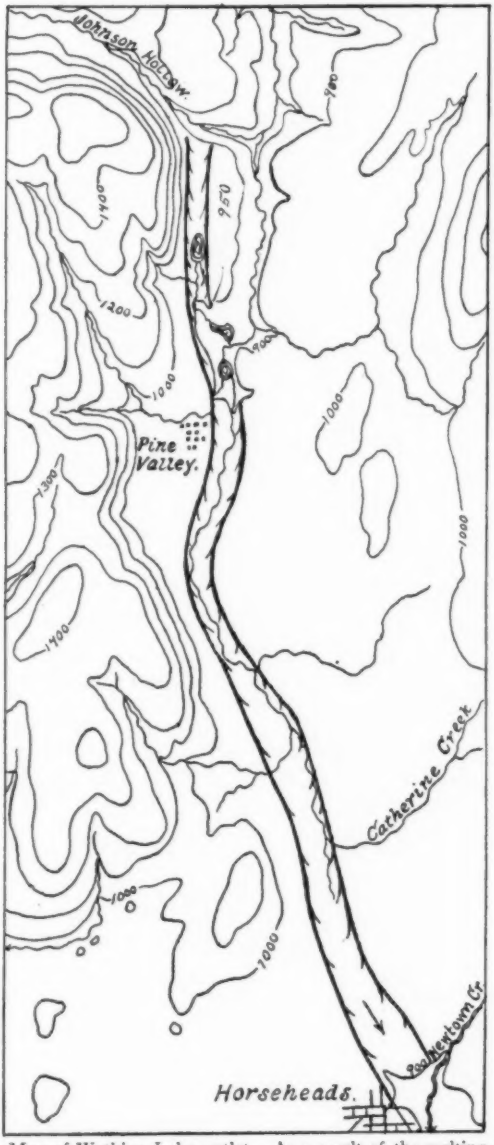

FIG. 7.—Map of Watkins Lake outlet. As a result of the melting-out of buried ice after the outlet waters had ceased flowing, one side and a part of the bottom of the channel just north of Pine Valley has dropped out. Scale 1/62,500.

slight gradient northward as far as Pine Valley where the glacial lake properly began, as to the south into Elmira."

The failure of these authors to recognize the true beginning of the channel is probably due to the peculiar drainage condition now prevalent in the channel. Two miles north of Horseheads, Catherine Creek enters the old channel and, turning northward, follows it with very slight gradient as far as Pine Valley, where, one-half mile north of the village, its grade suddenly becomes steeper as it leaves the channel and flows the remainder of the distance to Seneca Lake delta through a deep drift valley (Fig. 7).

The question at once suggests itself: Why does Catherine Creek flow northward in the channel in a direction opposite to that taken by the glacial waters? Tilting of the land may be suggested as an explanation, for it is well known from the studies of Gilbert that this part of New York has suffered deformation since glacial times. Tilting, however, does not offer a solution of the problem, for the land was tilted toward the south, with uplift in the north. This would increase the grade of the channel rather than decrease it sufficiently to cause a reversal of drainage. A more satisfactory explanation may be found in the fact that Newtown Creek, which enters the channel at Horseheads, has built a fan across it, and by ponding back the normal stream in the channel has caused the reversal of drainage. Were it not for this fan, if a lake were now held up in Seneca valley, it would outflow at Pine Valley. Nevertheless, in glacial times the outlet was not here but was one and one-half miles north of the village close to the base of the steep hill at the mouth of Johnson Hollow.

The channel at the beginning has a width of 700 feet; gravelly bottom and distinct, clear cut, and approximately straight banks from fifteen to forty feet in height. At the first road crossing, one mile below the beginning, a small stream entering from the hills on the west has built a very perfect alluvial fan entirely across the channel and caused the formation of the shallow pond shown in Fig. 8. Below this the channel continues for about one-half mile to near the road leading into Pine Valley. For the next half-mile southward through the village one side of the channel and a part of the bottom have literally dropped out. Near the road the west bank and the west half of the channel are intact; the east half of the bottom and the

east bank have dropped down, leaving a depression now occupied in part by a pond at a level three or four feet below that of the channel bottom. Into this depression and its continuation northward Catherine Creek now flows. It is here that Watson and Fairchild evidently placed the outlet of Lake Watkins.

Obviously there has occurred here a settling-down of a portion of the drift in the central part of the valley since glacial times; cer-

FIG. 8.—Watkins Lake outlet. Looking up-stream from a point one mile below the beginning. The shallow pond in the foreground is caused by the blocking of the channel by an alluvial fan.

tainly since the waters of glacial lake Watkins ceased flowing through the channel, for had the settling occurred while the stream was still flowing, the depression thus formed would immediately have been filled with gravel. Besides, had the depression existed then as now the lake would have overflowed at this point rather than at a higher level farther north.

The melting of an ice mass buried beneath glacial gravels is sug-

gested as the cause of the settling.[1] Ice thus buried would melt away very slowly. In this case it must have remained at least until the glacier had withdrawn far enough to permit the waters of Lake Watkins to find an outlet at a lower level.

The conditions at Pine Valley and northward to Seneca Lake are especially favorable for the burial of an ice block. In this part of Seneca valley, which is comparatively narrow and gorge-like, there lay a long tongue of ice. The valley is now drift-filled to an unknown, but certainly great, depth, at least several hundred feet as is indicated by borings at Watkins and Pine Valley. Presumably at the time of maximum glaciation the ice completely filled the valley down to the rock at the bottom. As the glacier retreated, melting would take place largely at the surface, or at least more rapidly at the surface; with the result that at the surface retreat would be more rapid than deep in the valley bottom. Since the glacial waters escaped to the south at a level certainly considerably higher than that of the bottom of the ice, outwash gravels from the more rapidly melting upper part would spread over and bury the lower ice. Ice thus buried would melt away slowly and in melting allow the settling of the overlying drift; producing conditions like those actually found at Pine Valley.

The topography strongly indicates that the axis of Seneca valley for several miles north of Pine Valley was occupied by an ice-block which in melting allowed the slumping of the overlying drift.

THE JOHNSON HOLLOW CHANNELS

At the head of Johnson Hollow (Watkins sheet), is an important series of connected channels illustrating four of the types described in the preceding pages, and showing their relations to each other and to the ice front. (See map, Fig. 9.)

At the time the channels were forming, a lobe of ice from the main Seneca valley tongue pushed into the Moreland valley; ending near the head of Johnson Hollow. At the same time the ice in the Seneca valley extended several miles farther south. The drainage from the margin and end of the Moreland lobe, together with a lateral stream (*E*) from the Seneca valley tongue, united at the head of Johnson

[1] The agency of a buried ice mass had been suggested by Tarr as an explanation of this particular condition, even before the direct evidence of the sinking of the channel bottom had been found.

Hollow and flowed as a single large stream, southward and southeastward to the foot of the hollow where it emptied into a marginal lake held up by the ice of the Seneca valley tongue.

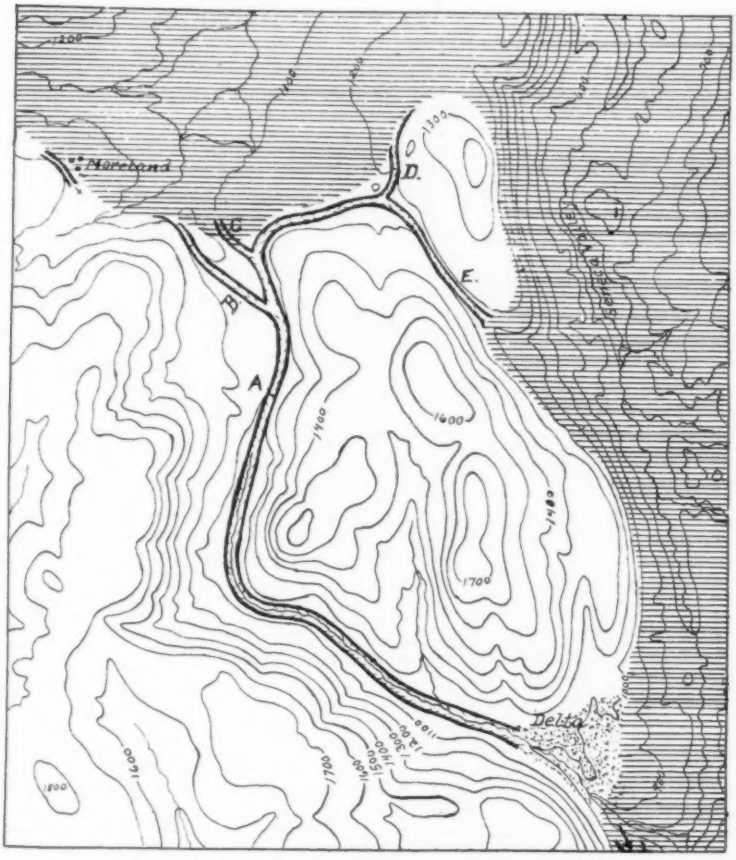

FIG. 9.—Johnson Hollow Channels. The probable position of the ice at the time the channels and delta were forming is shown by the ruled area. The Watkins Lake outlet begins at the base of the hill near the southeast corner of the map. Scale 1/62,500.

Four of the channel types, *marginal*, *lateral*, *morainic*, and *lake outlets*, are represented in this series. Channel *B*, at the beginning,

is strictly marginal. Farther down it swings behind a low knoll probably of rock; then takes a straight course southeastward to the main channel. *C*, which was probably initiated by a stream flowing from the end of the ice-lobe, seems later to have developed into a lake outlet, draining a lake held up in the Moreland valley by the retreating Moreland lobe. Channel *D*, formed along the eastern margin of the Moreland lobe, may be classed as marginal-morainic. It enters the main channel *E* as a rather deep trench with banks only moderately trimmed. Its lower portion might well be mistaken for a small valley cut by a post-glacial stream were it not for the fact that the only stream, a very small one, which enters it has built a fan across it. In its upper part the channel becomes shallower and finally one bank, the western, disappears. The other continues for considerable distance farther, gradually becoming less and less distinct.

E has already been described (p. 539). The main channel below A, is very pronounced, flat bottomed, and from four hundred to six hundred feet in width, with sharply trimmed drift banks twenty to thirty feet high.

An interesting drainage condition is found in connection with these channels. One-half mile below the junction of *A* and *B* a stream from the hills on the east has built a fan entirely across the channel. This has completely reversed the drainage of the channels above the fan, causing all the water to flow out northward through *C*, and thence to the stream in the Moreland valley. The grade of *C*, which was doubtless a lake outlet, is so low that a slight blocking of the channel three-fourths of a mile below was sufficient to reverse its stream.

In so far as could be determined, these channels were practically contemporaneous in origin, except that *C* must have persisted longer than the others. There is no apparent hanging condition at the junction of any of the channels with the main one as might be expected if the stream in one ceased flowing for any considerable time before that in the others.

At the foot of Johnson Hollow is a large delta formed, apparently in a marginal lake, by the stream flowing down the channel. The top of the delta is at the 1,000 feet contour, with the northern part slightly lower than the southern. The delta is very perfect, with

an even slope eastward toward the ice. There is evidence that this delta was built against the ice. Its eastern margin shows several deep kettles and other signs of the melting out of buried ice.

The top of the delta is one hundred feet higher than the Watkins Lake outlet channel, which began only three-fourths of a mile distant. This indicates clearly the deposition of the delta material in a marginal lake rather than in Lake Watkins. There is good evidence that while a large stream was still coming down Johnson Hollow, the ice melted out sufficiently from Seneca valley to cause the draining of this marginal lake and to bring about the initial stage of Lake Watkins at a level one hundred feet lower. At this level, just opposite the beginning of the outlet channel is a second delta built into Lake Watkins by a stream from Johnson Hollow. While forming the lower delta the stream cut a broad channel though the one first formed.

The Johnson Hollow series of channels presents many features of interest. It shows that while an ice-tongue lay in Seneca valley, at least as far as Millport, a lobe pushed westward into the Moreland valley and ended approximately at the head of Johnson Hollow. It also illustrates the case of a stream leaving the ice at one point and returning to it at a lower level several miles distant. This gives a means of estimating the ice slope, which seems to have been about sixty-six feet per mile. There is a possibility, however, though from the evidence it seems very improbable, that, while the upper delta was building in the marginal lake, the ice-lobe from which the stream came pushed for considerable distance into Johnson Hollow; and that it was only during the building of the later delta in the early stage of Lake Watkins that the channels at the head of Johnson Hollow were formed. If this were the case, the ice margin might have had a considerably greater slope, for the ice-tongue would not then necessarily reach as far south as the delta.

SUMMARY

Our study of the Finger Lake channels has brought out some features of interest and importance. It has shown, in the first place, the large number of these channels. It has shown also that, although from their nature the greater number of the channels now visible were formed during the final retreat of the ice, a considerable per-

centage have an earlier origin. In some of these cases all that can be said concerning the time of their formation is that they antedate the final retreat of the last ice-sheet. In others, notably Cayuta Gorge channel, the development of tributary gorges subsequent to the channel cutting points unquestionably to one or more interglacial intervals at least several times longer than post-glacial time.

Clear evidence of the burial and subsequent melting of large ice masses, with consequent settling of the overlying drift, has been found in one of the channels. Under ordinary conditions it would be difficult to obtain conclusive evidence of settling caused by melting ice because of the difficulty of distinguishing the resulting depressions from normal morainic topography. When, however, such a sinking lowers a portion of the bottom of a large stream channel, the evidence is clear.

One of the most important features of these channels is that they show the direction of the ice flow, and in this are of great value in the mapping of the glacial geology of a region. In favorable cases, especially in connection with *lateral* channels, it is possible to ascertain the slope of the ice with a very fair degree of accuracy.

Glacial channels are easily recognized. They are characteristically flat bottomed and are usually swampy. The banks, in almost all cases, are distinct and, except where disturbed by cultivation, show little effect of post-glacial degradation.

RELATION OF WIND TO TOPOGRAPHY OF COASTAL DRIFT SANDS

PEHR OLSSON-SEFFER
Mexico City

The work on which this paper is based covers a number of years and a variety of marine sea-coasts. Sand formations have been studied by the writer on different coasts in Europe, on sea-shores in Australia, South Sea Islands, North and Central America. In a recent paper[1] the origin and development of such sand formations have been discussed and it is the intention to present here some observations on the wind in its relation to the topographical features of these sands.

As a geological agent the wind exercises a considerable modifying power, although its character is very unsteady. It manifests its influence by carrying fine particles of soil, depositing these, denuding rocks that stand in its way, and indirectly affecting the topography of the earth's surface by distributing moisture and limiting vegetation.

The moving sands of sea-shores afford ample opportunity for study of the methods of the wind in its work of denudation. It can often be seen how the sand carried over the surface of rocks sometimes wears them quite smooth, or covers them with scratches and furrow marks. This abrasion by the wind-transported material is always noticeable in dune districts, at least on the wind-worn pebbles, but also on the remains of trees which have been partly buried by the drifting sand, and then the protruding parts have been slowly carved and worn by the sand (Fig. 2).

In its weathering action wind has a constant tendency to break down the stones, gravel, and coarser soil particles into fine dust, and it is assisted in this work by the moisture. If it was not for the looseness of the sand, which allows the rain to percolate rapidly and thus to carry the fine dust deep into the ground, the persistent combined action of wind and moisture would suffice to prepare the quantity of

[1] Pehr Olsson-Seffer, "Genesis and Development of Sand Formations on Marine Coasts," *Boletin de la Sociedad de Geográfia y Estadistica*, Mexico (in press).

fine material needed to supply plants with soluble substances, and thus to allow a cover of vegetation to gain a foothold.

The action of wind as a transporting agent when removing the denuded rock material, whether soluble or insoluble, as soon as it appears at the surface is one of the most important factors in the denudation processes. Walther[1] calls this phenomenon *deflation* and he considers it to be of even more consequence than abrasion. Through deflation fresh rock is consequently exposed to the eroding forces, and it is evident that this action must be considerable, especially on the coasts with their moist climate.

The softer strata of rocks are worn more deeply by deflation, co-

FIG. 1.—Established and rejuvenated dune surface at Fremantle, Western Australia.

operating with abrasion, and the harder layers are left to form cornices. On account of the abrasion being greater near the surface where the wind current carries a greater load of sand, the lower parts of rocks are often eroded more rapidly than the upper. Evidence of this can be seen in the "balancing rocks" not infrequently occurring in the neighborhood of extensive sand formations. The writer has seen such rocks on many coastal sands, near Port Fairy in Victoria, for instance, on the West Australian coast, at Port Said in Egypt, and at Carmel Bay in California.

It is especially the fine particles of sand which are liable to be transported by the wind; but as the fine sand retains its moisture better

[1] *Das Gesetz der Wüstenbildung*, 1900.

than that of coarser texture, because of its greater capillarity, it is evident that, if some means are furnished which increase the amount of moisture, or rather lessen the evaporation, the action of wind will be in a measure counterbalanced. This is accomplished by a vegetative covering, which fixes the sand and thus protects it against the influence of the air currents. The climatic conditions, especially a larger or smaller degree of moisture, is therefore a great factor in the development of eolian sand formations.

It is a matter of everyday observation that the velocity of the wind changes rapidly and varies considerably. A wind which appears to be very uniform is, when subjected to close observation, only a series of gusts following each other with intervals of lesser velocity, and even of complete calm. The carrying capacity of the wind is, therefore, also very variable. The wind that one moment carries and drops pebbles, a few minutes later carries only sand for deposition, and finer sand follows coarser.

A series of observations made by the writer in this connection will here be referred to.

Methods of observation.—The experiments were conducted on the sandy beach north of Fremantle in Western Australia during September and October, 1902, and they were intended to ascertain the carrying capacity of wind of certain velocities, as well as the effect of these winds on the movements of the sand.

For measuring the velocity of wind I used anemometers of Crova type, purchased from Negretti and Zambra in London. The instrument was placed on a support steadily secured in the sand, and elevated 5 cm. above the ground. It was not practicable to lower the apparatus more, because nearer the surface the amount of sand particles carried by the air current was still greater than at the elevation chosen, and I found that the results were somewhat influenced by the density of the sand-shower.

Samples of sand of different grain sizes were secured by sifting through sieves with meshes of known diameter. Three sizes were used, 0.2 mm. (fine sand), 0.3 (medium sand), and 0.6 (coarse sand).

Of each kind of sand a quantity of about 5 cu. dm. was dyed with different colors, black, bright blue, and orange being considered the most suitable and best distinguishable from the natural sand. The

sand was dyed in colored water and then thoroughly dried. By weighing the colored sand I satisfied myself that the weight had not materially increased through this process. At the time the observations were made, this colored sand was laid out in ridges transverse or parallel to the direction of the wind or in small heaps, the different results being noted in each case.

In order to ascertain the height to which different grades of sand were lifted by the wind I devised a simple contrivance, which seemed

FIG. 2.—Established dune destroyed by the wind. Near Southport, Queensland.

to fill the purpose. Five sheets of corrugated iron held together by a frame, were placed above each other at a distance of 2 cm. with the lowest floor resting on the ground, and with the wrinkles at right angles to the direction in which the sand moved. The front of each sheet was flattened for about 12 cm., so as not to give any obstruction to the wind or sand. These sharp, parallel edges divided the sand-shower, and the grains were collected in the folds of the apparatus. By closing the front and sweeping the different "floors" samples for examination were secured. For the sake of brevity I have in the following pages spoken of this apparatus as the "sand separator."

As my object was principally to find out the influence of wind in the layers near the surface or those which carry the greatest quantity of sand and come into contact with the lowest strata of the vegetation, I did not have the sand separator arranged to receive sand which was lifted higher than 8 cm. above the surface.

It seemed, further, to be of considerable interest to know how great the difference of the velocity of wind was on level and broken ground, and consequently to what extent a rough surface influenced the movement of sand. On a vacant lot, south of Fremantle, where the sand had been covered with a layer of loam for agricultural purposes, I had opportunity to make some observations in that direction, and subsequently I measured the surface velocity of air on a grassy plot adjoining a field of drifting sand.

Day after day the experiments were continued under different conditions of wind and humidity, and with the aid of an assistant I was able to make careful observations of the tactics of the moving sand, and to secure some results which are not without interest.

Velocity of wind.—Of the hourly registrations made, those for six days will be given as samples. The place of observation was on an open beach, 40 m. from shore. Angle of sloping about 12°. The following table indicates the result. Velocity in meters per second.

	I	II	III	IV	V	VI
7 A.M.....	0.6	11.3	10.9	8.6	3.1	10.4
8	1.3	12.5	12.3	12.7	3.9	10.9
9	1.9	13.1	14.2	14.1	4.7	11.5
10	2.4	13.8	15.7	14.9	5.6	14.2
11	2.1	14.6	18.2	23.7	7.1	15.7
12	4.5	15.9	19.5	22.5	7.6	18.6
1 P.M.....	4.9	17.6	16.3	23.2	7.9	18.9
2	6.0	19.4	14.9	14.1	8.7	17.2
3	12.8	22.4	15.1	22.6	12.3	18.4
4	13.9	21.2	15.6	22.3	14.1	20.2
5	13.7	19.6	13.2	14.7	11.6	19.7
6	13.3	18.3	12.9	20.4	8.7	16.1

Result of experiments on carrying capacity.—A few of the observations made will here be given to show the details obtained. The Roman numerals refer to corresponding days in the table of velocities.

I. No drifting was observed in the forenoon. Slight movement was noticed between 1 and 2 o'clock. During the next hour the sand

separator had received a quantity of grains on each floor. Mechanical analysis of these grains showed that on the lowest floor A, on a level with the surrounding ground where the greatest quantity of sand had collected, many different grades were represented. This is self-evident as the grains here had only rolled and not been lifted by the wind; at least not higher than 2 cm., in which case they were intercepted by the next higher floor B. The wind was gusty, but the force of the separate gusts was comparatively uniform, and the intervals of wind of lesser velocity, brief and somewhat regular in length.

PERCENTAGE OF DIFFERENT GRADES

	Diameter in mm.	Per Cent.
Floor A.	0.02–0.05	trace
	0.05–0.1	2.2
	0.1 –0.2	13.1
	0.2 –0.3	56.2
	0.3 –0.5	21.5
	0.5 –1	5.6
	1 –2	1.4
Floor B.	0.02–0.05	0.8
	0.05–0.1	5.2
	0.1 –0.2	42.9
	0.2 –0.3	44.5
	0.3 –0.5	6.6
Floor C.	0.02–0.05	12.3
	0.05–0.1	16.6
	0.1 –0.2	58.4
	0.2 –0.3	10.7
	0.3 –0.5	2.0
Floor D.	0.02–0.05	37.4
	0.05–0.1	56.7
	0.1 –0.2	5.9
Floor E.	0.02–0.05	72.5
	0.05–0.1	26.3
	0.1 –0.2	1.2

The coarsest material with certainty lifted by a wind of a velocity of 12.8 m. per second was, as indicated by the above table, medium sand, and the greatest height to which this sand was lifted, 4–6 cm.

During the same period of time the colored sand samples exposed to the wind were distributed as follows:

Fine sand	12 m.
Medium sand	12
Coarse sand	7.5

II. During morning hours the drifting was insignificant as the surface of the ground was still somewhat moist with the abundant

dew fall. But at 9 o'clock, although the force of wind had not increased much, the sand was moving briskly and the shifting continued through the day.

The sand separator was kept at the same distance from shore as on day I, but the ground was so slightly sloping as to be almost horizontal. The day was warm and the sand quite dry. From 2 to 3 o'clock the separator was in action, and subsequent analysis gave the following result:

PERCENTAGE OF DIFFERENT GRADES

Diameter in mm.	Per Cent.
Floor A.—0.02–0.5	trace
0.05–0.1	6.4
0.1 –0.2	10.2
0.2 –0.3	41.3
0.3 –0.5	28.4
0.5 –1	9.6
1 –2	3.5
2 –4	0.6
Floor B.—0.02–0.05	1.7
0.05–0.1	3.3
0.1 –0.2	26.5
0.2 –0.3	47.8
0.3 –0.5	14.1
0.5 –1	6.6
Floor C.—0.02–0.05	5.1
0.05–0.1	10.0
0.1 –0.2	23.4
0.2 –0.3	41.2
0.3 –0.5	6.7
0.5 –1	3.6
Floor D.—0.02–0.05	16.3
0.05–0.1	34.7
0.1 –0.2	28.5
0.2 –0.3	12.1
0.3 –0.5	8.4
Floor E.—0.02–0.05	32.5
0.05–0.1	34.1
0.1 –0.2	16.8
0.2 –0.3	5.4
0.3 –0.5	1.2

A wind with a velocity of 22.4 m. per second was thus able to lift medium sand at least 8 cm. and coarse sand 4–6 cm. The coarsest grains at all raised above the surface had a diameter of 1 mm.

As for the distance to which the wind was able to transport colored grains I found grains 4.3 m. away from the original place of exposure after 15 minutes, while grains of 0.2 mm. diameter were carried at

least as far as 12 m. where they were intercepted by a white canvas sheet. These distances are only relative values of the carrying capacity, as they show only what has been observed with the crude methods employed; a number of grains are, no doubt, carried much farther but cannot be distinguished on the sandy ground.

IV. From about 8:15 A. M. the sand was drifting slowly, increasing by degrees with the increase of force of wind and the rise of temperature and consequent desiccation of the sand. Shortly after noon a damp fog came driving inland from the ocean, and a decrease in the movement of the sand was at once evident. A small shower of rain followed and drifting ceased completely. Evaporation was not sufficient to dry the sand during the rest of the day, and in spite of the comparatively high wind no more drifting was observed.

VI. Between 10 and 11 o'clock in the forenoon the separator was at work, and collected samples of sand, the mechanical analysis of which is given below. The sand was completely dry to a depth of about 5 cm. and the separator was placed on ground sloping in an angle of 25 degrees.

PERCENTAGE OF DIFFERENT GRADES

	Diameter in mm.	Per Cent.
Floor A.	0.02–0.05	trace
	0.05–0.1	1.6
	0.1 –0.2	10.5
	0.2 –0.3	60.1
	0.3 –0.5	17.8
	0.5 –1	6.7
	1. –2.	3.3
Floor B.	0.02–0.05	trace
	0.05–0.1	3.8
	0.1 –0.2	37.3
	0.2 –0.3	51.9
	0.3 –0.5	7.0
Floor C.	0.02–0.05	5.7
	0.05–0.1	12.4
	0.1 –0.2	61.3
	0.2 –0.3	14.5
	0.3 –0.5	6.1
Floor D.	0.02–0.05	21.3
	0.05–0.1	63.9
	0.1 –0.2	12.6
	0.2 –0.3	3.2
Floor E.	0.02–0.05	64.8
	0.05–0.1	28.6
	0.1 –0.2	5.1
	0.2 –0.3	1.5

A wind with a velocity of 15.7 m. per second was thus able to lift grains of 9.3 mm. diameter to a height of 6–8 cm., and experiments for ascertaining the distance to which such grains were carried by the same wind showed this to be 8.6 m. in 30 minutes.

The few examples given are typical of a larger number (24) of mechanical analyses of series of samples collected with the sand separator during wind of different strength, but it is hardly necessary to furnish additional data, as a discussion of the facts given will bring out the points wanted for our present purpose.

For the solution of the problem of the carrying capacity of the wind, it is of primary importance to know whether the velocity is changing on or near the surface. Among the observations on velocity of wind in different heights, which have been recorded, we may mention those by Stevenson, Montaigny, Ragona, and Sokoloff. All these experiments show that *the velocity increases considerably with the height.*

A very significant feature of the above tables is that the bulk of sand on the two lowest floors is of such uniform size. I take this to indicate that the velocity of the lowest layers of air must be comparatively uniform, while the higher currents are of a more gusty character and are able to pick up the smaller grades of grains and lift them higher. It is an accepted fact that a current, which carries a load, is retarded, and the retardation is greater the larger the particles moved. Nearest to the ground there is a layer which on account of the friction against the uneven surface is comparatively inert, and we know that the velocity of the current in this layer increases only at a very slow rate with an increase in the speed of the layers next above it.[1] These circumstances put together tend to support the above theory that the movement of the lowest layer of the atmosphere is more uniform than the higher.

Although the bulk of sand on the lowest floor of the separator is greater than on any of the higher, the difference between the quantity of sand on A and B is not very remarkable. I understand this to prove that the larger part of sand moved by the wind is lifted from the ground, if only for a short distance. It seems at first sight as if all the material on the lowest floor or on the same level as the ground,

[1] J. A. Udden, *The Mechanical Composition of Wind Deposits*, 1898, p. 24.

had been pushed forward or rolled on the surface. But the opening between the floors is high enough to allow a considerable part of the grains to be lifted above ground. It seems most likely to me that the sand is moving in short jumps.

Different opinions have been expressed on this question. Brémontier considered that the sand is not lifted to any considerable height as he says:

> Chacun des grains de sable dont elles (les dunes) sont composées n'est pas assez gros pour résister aux vents d'une certaine force; ni assez petit pour être enlevé comme de la poussière, ils ne font que rouler sur la surface dont ils sont arrachés, s'élèvent rarement à plus de 3 à 4 pouces d'hauteur.[1]

Andersen[2] also maintains that the grains are mostly rolled on the surface. Berendt, Hagen, and Sokoloff, among others, admit that it is lifted quite high; the latter[3] correctly assumes that the many different theories on this question most likely depend on the fact that the observations refer to different places on the dunes sometimes to the front slope, in other cases to the summit or to the leeward side.

Udden[4] discusses this question in following words:

> Materials finer than dune sand are wholly lifted up into swifter currents which promptly move them. The dune sand itself, on the other hand, is partly lifted and also partly rolled just as the grains of the nearest larger sizes. Working in this last manner the transporting power of the wind varies more nearly in approximation to its erosive force than to its lifting force. With changes in velocities the latter varies as the sixth power while the erosive force varies as the square. It is therefore much easier for the coarser ingredients to be rolled along with the dune sand than it is for the dune sand to be picked up and carried away with the finer ingredients.

This holds true and the cause of the greater resistance of the finer material is simply the greater coherence of the finer soil particles. In drawing any inferences with regard to these matters we must not forget, however, the influence which is exerted by the slope. On a horizontal surface the effect of wind is not so great as on a slope.

[1] "Mémoire sur les dunes," *Ann. des ponts et chaussées* (1), 1883, p. 148.

[2] *Om Klitformationen*, 1861, p. 57.

[3] Sokoloff, *Die Dünen*, 1894, p. 79.

[4] *The Mechanical Composition of Wind Deposits*, 1888, pp. 24 ff.

This has been shown by Sokoloff[1] and two of the experiments already described, those on days I and II, illustrate the same fact. Although in the latter case the wind was swifter with nearly 10 meters per second the quantity of material moved as well as the percentage of the coarser grades was only very little larger than in the former case, when the separator was placed on a sloping surface.

Any obstruction that comes in the path of the wind will greatly reduce its force and consequently lessen the movements of the sand. It is on this principle that some of the methods of arresting drift sand are based. Planting rows of grasses or trees, or the making of fences of sticks and other material on the dunes are means employed for this purpose. Scanty rows of grasses act more effectively as windbreaks than as regular binders of the soil, and in planting such "sandstays" it is important to get the right distance between the rows, which varies at different localities with the exposure to wind and coarseness of the sand. If the local conditions have not been studied and if the disposal of the windbreaks has not been done properly, the results will be unsatisfactory. Too long distance between the rows will not prevent drifting, and too close planting is unnecessarily expensive.

The experiments conducted for the purpose of ascertaining difference in velocity of wind on an even and a rough surface gave the results shown below:

Number of Series	Number of Observations	Mean Velocity per Second in Meter		
		On Even Surface	On Rough Surface	On Grass Covered Surface
I.....	7	8.4	5.2	4.3
II.....	11	10.2	6.8	5.8
III.....	5	4.6	3.1	2.6
IV.....	6	9.8	6.3	5.1
V.....	3	16.2	10.6	8.7
VI.....	6	5.4	3.7	3.0

The following compilation of these results will show the actual difference of velocities as well as the proportion expressed in per cent. of velocity on the even surface.

[1] *Die Dünen*, 1894, p. 289.

DIFFERENCE OF WIND VELOCITIES PER SECOND IN METER

Number of Series	Between Even and Rough Surface		Between Even and Grassy Surface		Between Rough and Grassy Surface	
	Actual Difference	Per Cent.	Actual Difference	Per Cent.	Actual Difference	Per Cent.
I.....	3.2	61.9	4.1	51.1	0.9	82.6
II.....	3.4	66.6	4.4	50.8	1.0	85.2
III.....	1.5	67.5	2.0	56.3	0.5	83.8
IV.....	3.5	64.2	4.7	52.0	1.2	80.9
V.....	5.6	65.4	7.5	53.7	1.9	82.0
VI.....	1.7	68.5	2.4	55.5	0.7	81.0

In these experiments the anemometers were placed on a board on the ground, thus raised 3 cm. above the surface. The centrum of the instrument was on a level with the top of the low grass turf in the case of the grassy surface.

We find from these accumulated facts that the mean velocity on the even surface surpassed that on the rough ground by 3.15 m. per second or 34.7 per cent. F. H. King[1] gives the velocity over smooth ground as more than 40 per cent. greater than that on a rough surface. The difference in my results may have been caused by different conditions under which the experiments were conducted. King does not give any information about the method by which his results were obtained so that actual comparison is impossible. I consider the difference as being of minor importance, as by both these series of experiments it is clearly shown that the velocity of wind over a smooth surface is *at least* 34.7 per cent. greater than on uneven ground. Again, the velocity on grassy ground is still less than on bare rough surface. This is a fact of some practical importance in connection with planting on sandy soils, and it has a bearing of considerable weight on the vegetation on sand formations.

Through the investigation of Kihlman,[2] Warming,[3] Hansen,[4]

[1] *Destructive Effects of Winds on Sandy Soils and Light Sandy Loams with Methods of Prevention*, Eleventh Annual Report of Agricultural Experiment Station of Wisconsin University, 1895, p. 332.

[2] Pflanzenbiologische Studien aus Russisch Lappland," *Acta Soc. F. Fl. F.*, VI, 1890.

[3] *Plantesamfund*, 1895; "Der Wind als pflanzengeographischer Faktor," *Engl bot. Jahrb.*, Vol. XXXI, 1902.

[4] *Die Vegetation der ostfriesischen Inseln*, 1901.

and others, it is now a well-established fact that the movements of the atmosphere are of the greatest importance for the plants, especially because of the influence of winds on the transpiration processes. With regard to vegetation on coastal sands wind is a factor of particular moment. The difference in wind velocities on open soil, on a surface more or less uneven, or covered with a more or less dense vegetation, is therefore of great significance, and we shall be able to show some effects of this eolian influence in the following pages.

The direction of wind on different shores is further a factor which must not be overlooked as it plays an important rôle, not only in the development and topography of the sand formations, but also in the distribution of plants on the coast.

As a general rule we can lay down the law that on every coast where sand dunes occur the offshore wind is prevailing. There are, however, a great many exceptions to this rule, where the local topography or other factors have been the cause of dune development.

On some coasts, as that of Jutland, where the supply of marine sand seems to be inexhaustible, the prevailing westerly winds from the sea drive the sand inland from the beach, continuously adding to the volume of sand. On other coasts, as that of Gascony, strong land winds occur, which often return considerable quantities of sand to the sea.

On the Pacific coast of America near San Francisco, and near Salina Cruz in Mexico I noticed that the sand cast upon the beach by the northerly and westerly winds was again driven back into the sea by the winds from the south and east. Similar conditions exist on many other coasts where the topography is favorable to such a forward and backward movement.

The force of the wind is augmented or diminished according to the season, but the result as regards sand formations depends greatly upon the direction of the coast. On the windward side of many islands high dunes are formed, as for instance on the northern coast of Oahu in the Hawaii group where they reach about 30 feet.

Typical coastal sand formations.—Very little variation is noticed in the formation of sand drifts on marine coasts. Wherever the drifting sand encounters an obstacle in its way such as a shrub or a piece of wood, or a rock, there it deposits on the leeward side. Gener-

ally we meet, however, with a level beach of a varying width, and then the coastal dune rises slowly at an angle varying from 4–16° on the wind side. Its height varies on different coasts according to the supply of material and the prevailing direction of the wind.

On very long, straight, and open coasts the wind strikes the sand over a long distance with the same force and under almost identical conditions. On such coasts we find long stretches of dunes showing a little diversified topography. As a rule the dunes are very little curved and run at right angles to the direction of the wind.

The diurnal variation of direction and force of winds which always is considerable on marine coasts exercises some influence upon the development of the drift-sand formations. The angle of deflection from the direction of the annual wind resultant differs in summer and winter, and from observations of these meteorological data in a locality with drift sands it is possible to calculate to some extent as to the annual movement and changes of the sand formations.

Usually the downward eddy behind the coastal dune sweeps over the stretch of land immediately following, and regular dunes are not formed before some distance from the coastal dune. These first dunes are formed round some obstacle, and their form is usually oval, pointing toward the wind and the coast, but sometimes crescentic, and convex to the wind. These small advance dunes are followed by trains of large dunes, nearly uniform in shape. The wind sweeps with brisk velocity upward along the gentle gradient and carries the sand to the brink where it is deposited on the steep lee-side which is further increased by the undercutting of the eddy.

Beyond the reach and influence of the strong sea breeze the dunes are more irregular, and lateral inequalities are formed connecting the various individual dunes into long ridges. These travel forward in a continuous march, slowly but surely. The form and location of the drift changes gradually.

A dune region shows a more or less undulating surface, which suddenly may be broken up into quite high hills or ridges. Sometimes, when the forward march of the dunes has been stopped the dune belt is continued inland in a gently undulating sand field.

In a dune region many different stages of dune development are observed, from the embryonic living dune to the large established

mountain-like sand dune covered with vegetation. Very often such finished dunes are again broken up by the wind (Fig. 1). On these rejuvenated dunes the usual series of development takes place from the very beginning, and they have often a peculiar character, resulting from the remaining remnants of the old vegetation covering and the new plant immigrants which have arrived after the complete or partial destruction of the dune.

It is a rule that the inner dunes in a complex are higher than those nearer the beach because the horizontal directions of wind are deflected.[1]

Dunes do not travel extensively. Those in Brittany are said to move 27 feet a year for 200 years. On the coast of Norfolk facing the North Sea the dunes travel 150–80 feet a year, according to Lapparent. I have not been able to find conclusive evidence regarding a more rapid advance of dunes than 42 feet in one year, which is the rate of advance of some dunes near Vera Cruz in Mexico.

Dr. Baschin[2] reports a mean drift of moving sand ridges on the west coast of Fanö, the northernmost of the islands of North Friesland, of about 10 feet a day. The author's explanation is that on a large dune more material must be driven to the lee-side before any displacement of the crest becomes evident, while the small sand ridges on which his experiments were made moved more rapidly. He also maintains that the slope on the leeward side is due simply to the fall of the sand as the crest of the dune moves forward. I hold with Bertoldy that the steep slope is due not only to the fall of the sand but also to the effect of the vortex of air round a horizontal axis formed on the lee-side of the dune.

BIBLIOGRAPHY

ANDREWS, E. W. "Pebbles and Drifting Sand," *Trans. N. Z. Inst.*, Vol. XXVI, p. 397.

AUERBACH, FELIX. "Die Gleichwichtsfiguren pulverformiger Massen," *Ann. Physik*, Leipzig (4 Folge), Vol. I, 1901, pp. 170–219.

BOLTON, X. C. "Denudation," *Trans. N. Y. Ac. Sci.*, Vol. IX, 1889–90, pp. 110–26.

BRÉMONTIER, N. T. T. *Recherches sur le mouvement des ondes*, Paris, 1809.

[1] Franz Czerny, "Die Wirkungen der Winde auf die Gestaltung der Erde," *Peterm. Geog. Mitt.*, 1876, Ergänzh. 48, p. 27.

[2] *Zeitschrift der Ges. für Erdkunde zu Berlin*, No. 6, 1903.

CHOLNOKY, I. "Die Bewegungsgesetze des Flugsandes," *Foldt. Kozl. Budapest*, Vol. XXXII, 1902, pp. 6–38.

CORNISH, VAUGHAN. "On the Formation of Sand-Dunes," *Geogr. Journ.*, Vol. IX, 1897, pp. 278–302.

"On Desert Sand-Dunes Bordering the Nile Delta, *Geogr. Journ.*, Vol. XV, 1900, pp. 1–30.

DARWIN, G. H. "On the Horizontal Thrust of a Mass of Sand," *Min. Proc. Inst. C. E.*, Vol. LI, 1883, pp. 350–78.

DOSS, BRUNO. "Ueber Dünen der Umgegend von Riga," *Korr. Natf. Ver. Riga*, Vol. XXXIX, 1896, pp. 31–40.

HELMHOLZ, H. VON. "Die Energie der Wogen und des Windes," *Sitz. ber. Ak. Wiss. Berlin*, Vol. II, 1890, pp. 853–72.

KELLER. "Studien über die Gestaltung der Sandküsten," *Zs. Bauwesen*, Vol. XXXI, 1881, pp. 190–.

LABAT. "Les dunes maritimes et les sables litteraux," *Bull. Soc. géol. France* (3), Vol. XVIII, 1889–90, pp. 259–73.

LANGLEY, S. P. "The Internal Work of the Wind," *Am. Journ. Sci.*, 3d ser., Vol XLVII, 1894, pp. 41–63.

LORIÉ, J. "Binnenduinen en bodenbewegingen," *Tijdschr. aardr. genootsch.*, 1893, p. 753.

MERRILL, G. P., "Wind as a Factor in Geology," *Engin. Mag.*, Vol. II, 1896, pp. 596–607.

RECLUS, ELISÉ. "Etude sur les dunes," *Bull. Soc. géog. France* (5), Vol. IX, 1865, pp. 193–.

SAUER, A. AND SIEGERT, TH. "Ueber Ablagerung recenten Lösses durch den Wind," *Zs. d. geol. Ges.*, Vol. XI, 1888, pp. 575–.

SHALER, N. S. "Phenomena of Beach and Dune Sands," *Bull. Geol. Soc. Amer.*, Vol. V, 1894, pp. 207–12.

SOKOLOFF, N. A. *Die Dünen. Bildung, Entwickelung und innerer Bau*, Berlin, 1894.

STEENSTRUP, K. J. V. "Om Klitternes Vandring," *Nath. Medd. Kjobenhavn*, 1894.

THESLEFF, ARTHUR. "Dynbildningar i Oestra Finland," *Medd. Geogr. For. Finl.*, Vol. II, 1895, pp. 36–77.

WALTHER, JOHANNES. "Ueber die geologische Thätigkeit des Windes," *Natw. Wochenschr. Berlin*, Vol. XVI, 1901, pp. 431–32.

AN INTERGLACIAL FAUNA FOUND IN CAYUGA VALLEY AND ITS RELATION TO THE PLEISTOCENE OF TORONTO

C. J. MAURY
Ithaca, N. Y.

On the western shore of Cayuga Lake, in central New York, is an interglacial fossiliferous deposit which is of interest because of the rarity of similar beds which contain traces of Pleistocene life.

The deposit is between Taughannock Falls and Frontenac Beach in a small ravine which has cut through one of the delta terraces so common in Cayuga valley. It was first noticed some time since by Professor R. S. Tarr and was later examined by Professor G. D. Harris and the writer. The following is a vertical section of the locality.

Drift	20 to 30 feet
Gravel and sand	several inches
Fossiliferous clay	5 to 8 feet
Bowlder clay	10 to 15 feet
Devonian shales	10 feet exposed above lake level

The bowlder clay in its uppermost part passes into gravel and sand which are decidedly oxidized, indicating a period of erosion and weathering.

The clay in which the fossils are imbedded is a slaty blue color, loose and very peaty at the base where it is composed almost wholly of the remains of plants, but in the center it becomes compact and is a very fine-grained, blue clay. It is distinctly stratified and splits easily along the plane of bedding but not in any other direction.

Above the fossiliferous blue clay are a few inches of sand and gravel pointing to a short period of erosion at the close of the warm interglacial period before the return of the ice and the deposition of the great mass of overlying drift.

The fossils are all fresh-water shells. Unios, Anodontas, and Sphaeriums are common and of large size, showing that conditions were favorable for their growth, but few are well preserved.

The following species have been identified and are in the geological museum of Cornell University.

Anodonta fragilis Lam. (*marginata* Say)
Anodonta grandis Say
Anodonta grandis var. *footiana* Lea
Lampsilis luteolus Lam.
Lampsilis ventricosus Barnes
Sphaerium simile Say
Pisidium compressum Prime
Pisidium virginicum Bourg.
Limnaea palustris Mull.
Limnaea elodes Say
Physa heterostropha Say
Planorbis bicarinatus Say
Planorbis deflectus Say
Planorbis lentus? Say
Planorbis parvus Say
Amnicola limosa Say
Valvata tricarinata Say
Campeloma decisa Say

Of these species *Sphaerium simile*, *Pisidium compressum*, *Planorbis deflectus*, *Amnicola limosa*, and *Valvata tricarinata* are the commonest forms.

Every one of the species listed has been found, by the writer, now living in Cayuga Lake. But of the five Unionidae, four are Mississippi species which are, however, also living now in the St. Lawrence system. *Anodonta fragilis* is the only one that strictly belongs to the St. Lawrence. *Luteolus* though originally a Mississippi species has secured such a foothold in the St. Lawrence system as to have become one of the commonest shells of the Finger Lakes.

On comparing the Cayuga Valley Pleistocene shells with those of the well-known interglacial beds near Toronto, about 170 miles to the northwest of Ithaca, we find the following species common to both deposits.

Lampsilis luteolus Lam.
Anodonta grandis Say
Sphaerium simile Say
Pisidium compressum Prime
Limnaea elodes Say
Planorbis parvus Say
Planorbis bicarinatus Say
Amnicola limosa Say
Physa heterostropha Say
Valvata tricarinata Say
Campeloma desisa Say

Thus more than half the interglacial species found in Cayuga Valley have also been identified in the warm climate or Don valley beds of the Toronto formation.[1]

But while we find that every one of the interglacial species of Cayuga Valley are now re-established in Cayuga Lake, on the con-

[1] See A. P. Coleman, *Amer. Geol.*, Vol. XIII (1894), pp. 85–95; *Journ. Geol.*, Vol. IX (1901), pp. 285–310; also C. T. Simpson, *Proc. U. S. Nat. Mus.*, Vol. XVI, pp. 591–95.

trary, two-thirds of the Unios in the Don valley beds withdrew permanently from Lake Ontario after the destruction of their colonies. These forms required a milder climate and could only live in Ontario during the warm interglacial period when, as Coleman has shown, the climate of Toronto was so mild as to permit the growth of the paw-paw and the osage orange.

In addition to the similarity of faunas of the Don and Cayuga valley deposits, there is a great similarity of levels. According to Mr. Coleman the lowest of the Don valley beds was formed when the water stood 19 feet above the present level of Lake Ontario. The Cayuga valley deposit began to be formed with the water about twenty feet above the present lake level.

It is unfortunate that the plant remains in the Cayuga valley interglacial bed are too decayed and fragmentary for identification, but the lowest layers of the fossiliferous blue clay, like the lowest of the Don valley beds, are formed of sheets of vegetable matter consisting of twigs, fragments of leaves, and reeds.

In conclusion we may say that (1) the Cayuga interglacial colony was established by Mississippi and St. Lawrence molluscs which came down from the north and west; (2) this would have required a very considerable period of time after their widespread destruction in the preceding ice invasions; (3) the colony could not have been established during a slight oscillation northward of the ice (as might have been the case if the species had come in from the Susquehanna system); (4) more than one-half the molluscs found in the Cayuga valley deposit are reported from the Don valley beds of the Toronto formation; (5) the Cayuga and Don valley fossiliferous beds both began to be formed when the water stood about twenty feet above the present lake levels; (6) it is very probable that the Cayuga fossiliferous deposit corresponds approximately in time with the Don valley, or warm climate beds, of the Toronto Pleistocene formation which is regarded as representing the Peorian, or fourth, interglacial period.

AN EXAMPLE OF DISRUPTION OF ROCK BY LIGHTNING ON ONE OF THE LUCITE HILLS IN WYOMING[1]

V. H. BARNETT

The accompanying picture (Fig. 1) is a view on the summit of Cross Mesa,[2] one of the Lucite Hills near Rock Springs, Wyoming. This mesa, like most of the group, is quite barren and flat on top, the volcanic rock of which it is composed being unprotected by soil and vegetation. Like the other Lucite Hills it is a very prominent landmark standing well above the surrounding country.

The angular bowlders seen in the picture have been torn by some apparently violent force from the surface of the lava and some of them still lie in the cavity formed. The space from which the rock fragments were torn is roughly a half-saucer in shape, having the east rim nearly vertical while on the opposite side it is more gently sloping. Two or three cracks, one of which may be observed near the right lower corner of the picture, radiate from the saucer-shaped depression. Whether some of these cracks may not have occurred before the disruption the writer was not able to judge, but it is not likely that all of them did so occur. The rock fragments range in size from an inch or two in diameter up to about two feet and a half, and are sharply angular with fresh surfaces. From the size of the cavity the amount of rock removed is approximately twelve cubic feet and lies within a radius of about ten feet from the fracture and exclusively to the west of it. No fragments were observed to have been thrown very far.

Two hypotheses at once present themselves in explanation of this phenomenon: first, that of an artificial explosion as dynamite or blasting powder; second, that of lightning.

The probabilities of this being due to the first hypothesis seem very slight since it is so far removed from human activities of any

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] J. F. Kemp and W. C. Knight, "Lucite Hills of Wyoming," *Bull. Geol. Soc. Amer.*, Vol. XIV, 1902, p. 317.

kind. The nearest trail is in Long Cañon, one mile northwest and four hundred feet lower down. Over this trail there is perhaps not more than one person a week during summer and probably fewer in winter. Several coal prospects have been opened, however, during the last five or six years, in Back Cañon and also in Long Cañon, not more than five miles to the south, but giant powder only was used in shooting. Had a prospector been so disposed it is the writer's opinion he could not have produced the effect shown in this photograph with

FIG. 1.—View on top of Cross Mesa, Wyoming, showing fragments torn from the lava by lightning.

ordinary blasting powder. He certainly could not have done it without a drill hole and no evidence of holes were observed. Even with a drill hole it would have been very hard, if not impossible, to have confined the powder sufficiently well. Furthermore, from the very nature of the rock (lava), a prospector would not have been looking for minerals in this place, and if he had been doing it for amusement he almost certainly would have selected a crevice at the limiting cliff of the mesa where the explosion would have loosened a large mass of

rock and sent it tumbling down the steep slope which falls away from the escarpment.

The other hypothesis, that of lightning, seems the more probable, and the writer wishes to call attention to it as an example of a kind of phenomenon rather rarely noted in geological literature. A few instances of the disruptive effects of lightning are on record.

Hibbert[1] describes as follows the effect of lightning on the cliffs of micaceous schist on the east side of the island of Fetlar, one of the Shetland Islands.

> A rock 105 feet long, 10 feet broad, and in some places more than 4 feet thick, was, in an instant, torn from its bed, and broken into three large and several lesser fragments. One of these, 26 feet long, 10 feet broad, and 4 feet thick, simply turned over. The second, which was 28 feet long, 17 feet broad, and 5 feet in thickness, was hurled across a high point of a rock to the distance of 50 yards. Another broken mass, about 40 feet long, was thrown still farther but in the same direction, quite into the sea. There were also many lesser fragments scattered up and down.

T. R. Dakyns, in his paper on "Modern Denudation in N. Wales,"[2] says:

> During the great thunderstorm that occurred in N. Wales in the middle of August, 1898, a mass of rock was broken and thrown down the Llyn Teyrn. This is known to have been done by lightning, as it was not there until after the storm.

In a conversation with the writer, George Otis Smith has stated that during a thunderstorm in 1904, he observed lightning strike on the summit of Mt. Battie, in the northern portion of the Rockland quadrangle[3] (Maine), and a mass of quartzitic conglomerate several feet in diameter was broken from the glaciated surface and thrown out.

While the most commonly observed effects of lightning on rocks seems to be that of fusion resulting in the production of fulgurites or glassy coatings,[4] no evidence of fulgurites nor of glassy coatings was observed either on these fragments or in the cavity from which they were thrown, but since lightning of the disruptive type is apparently

[1] Samuel Hibbert, *Description of the Shetland Islands*, 1822, p. 389. For this account of lightning effect Hibbert says he is indebted to Geo. Low, *M. S. of Rev.*

[2] *Geological Magazine*, new series, Vol. VII, 1900, No. 1, p. 19.

[3] *Rockland Folio No. 158*, U. S. Geol. Survey, May, 1908.

[4] R. R. Julian, "A Study of the Structure of Fulgurites," *Jour. Geol.*, Vol. IX, 1901, pp. 673–93.

not always accompanied by high temperatures, it does not follow that this phenomenon may not have been caused by lightning.

The most evident effect of lightning is of the disruptive type observed almost every day in the form of splintered telegraph poles and shattered trees and buildings. Lightning, producing this class of results, does not seem always to be accompanied by high temperatures. The writer has observed one instance at least in which a perfectly dry wooden building was shattered without a tendency to firing it.

ON THE VALUE OF THE EVIDENCE FURNISHED BY VERTEBRATE FOSSILS OF AGE OF CERTAIN SO-CALLED PERMIAN BEDS IN AMERICA

E. C. CASE

In 1876–77 Cope referred certain beds in Illinois and Texas, bearing vertebrate fossils, to the Permian Age. This has stood almost without challenge until very recently and has had a very considerable effect on the literature of the Permian. The recent discovery by Mr. Raymond of reptilian remains, of the same character as those referred to the Permian from Illinois and Texas, in the Coal Measures of Pennsylvania[1] renders it desirable to re-examine the evidence upon which the position of the beds was determined. The conflicting evidence of invertebrates and plants will not be discussed as they will be considered in the accompanying papers.

In re-examining the evidence for the age of these beds it seems necessary to consider two points:

1. The morphological comparison of the North American forms with those of known Permian Age from Europe and other continents.

2. The possibility of the introduction of reptilian life at an age earlier than the Permian.

In discussing the first question it will be best to pass in review the evidence upon which Cope based his determination of the Permian Age of the beds. The scope of the article will not permit discussion of the details of comparative anatomy and so the arguments will be based on conclusions which have been reached by various anatomists, leaving the details to another time and place should a discussion arise.

Cope's evidence: The first mention of vertebrate remains from Illinois was in 1875:[2]

> A remarkable peculiarity of the vertebrae of the series is the longitudinal perforation axial of the centrum. They present the character observed in *Arche-*

[1] *Science*, Vol. XXVI, December 13, 1907.

[2] *Proc. Acad. Nat. Sci. Phil.*, 1875, p. 440.

gosaurus and other stegocephalous Batrachia, but which also exists, according to Gunther, in the living Rhynchocephalous lizard, the *Sphenodon* of New Zealand. The bones of the limbs and the scapular arches are decidedly reptilian, and so unlike those of any Batrachia with which we are yet acquainted, that I am disposed to refer them to the former class. And as there are several points in which the fossils resemble the order *Rhynchocephalia*, I refer them provisionally to that neighborhood. They constitute the first definite indication of animals of that type in the western hemisphere.

Associated with these saurians were found the teeth of two species of fishes which are important in evidence of the position of the beds in which they occur. One of these is a new species of *Ceratodus*, Ag., and the other a *Diplodus*. The former genus is characteristic of the Triassic period in Europe, one species having been found in the Oolite. It still lives in North Australia. In both of these respects the Rhynchocephalian lizards present a remarkable coincidence. They also belong to the horizon of the Trias in Europe; and the only living species is found in New Zealand. Thus it would seem that a fragment of this fauna, so ancient in the northern hemisphere, and so remarkably preserved in the southern, has been brought to light in Illinois. It must be added in reference to the geological age of the fossils, that the genus *Diplodus* has not yet been discovered above the Carboniferous, and that one genus of the *Rhynchocephalia* belongs to the Permian of Germany. We therefore wait further material before venturing to decide whether they belong to Triassic or Permian time.

In May, 1877, he read a paper before the American Philosophical Society in which he reaffirmed the probable Permian character of the beds:[1]

After an examination of the first fossils from this fauna which came under my observation, I left the question undecided as to whether its characters pointed to the Triassic or Permian Age. The Reptilia and a *Ceratodus* pointed to the former; the *Diplodus* pointed even to the Coal Measures. The additional evidence adduced in this paper adds weight to both sides of the question. Of the fishes added, *Ctenodus* is a genus of the Coal Measures, and while *Strigilina* is new, its affinities are to the Petalodont genera of that formation. On the other hand the reptilian character of *Clepsydrops* is established, and the number of its species is increased. Now the Coal Measures have nowhere disclosed reptilian remains, so far as we have determinations of a reliable character; Batrachia were the only type of air-breathing vertebrata known to that epoch. The present fauna must then be placed above the Coal Measures, and the horizon will correspond more nearly with the Permian than with any other embraced in the system.

From its most characteristic fossil, the bed might be called the *Clepsydrops* shale. Its position according to Dr. Winslow is near the top of the Coal Measures, and is marked No. 15, in Professor F. H. Bradley's section of the Coal

[1] *Am. Phil. Soc. Proc.*, 1877, Vol. XVII, p. 64.

Measures of Vermillion Co., in the *Report* of the Geological Survey of Illinois by A. H. Worthen, Vol. IV, p. 245. It is about 111 feet, averaging different localities, from the summit of the series, and 2,099½ feet from the base. Two insignificant beds of corals [misprint for *coal*] occur above and the following genera of invertebrate fossils: *Productus, Spirifer, Athyris, Terebratula, Hemipronites, Retzia, Zeacrinus, Cyathaxonia, Discinia, Lingula, Cardiomorpha, Orthoceras,* and *Nautilus*. Several of these genera are found in the Zechstein, while others belong to the Coal Measures and below them.

In another paper of the same year he says:[1]

Twenty species have now been obtained from the *Clepsydrops* shale, the exact geological position of which remains to be accurately determined. Dr. Winslow informed me that they are the bed No. 15 of Professor Bradley's section of the Carboniferous rocks of Vermillion Co., Illinois. This places them at the summit of the Carboniferous series, below two thin beds of coal. I am now informed that this portion of Professor Bradley's report is not correct, and that No. 15 occupies a much higher position than he assigns to it. It lies unconformably above the meron sandstone of Mr. Collett, which deposit is above the Coal Measures and unconformable to them. The stratigraphic evidence is thus confirmatory of that derived from paleontology, that the *Clepsydrops* shale occupies a position in the scale above the Coal Measures.

A page or two farther on in the same article he correlates the Texas and Illinois horizons (p. 193):

The discovery of a species of the genus *Clepsydrops* in Texas, in a formation hitherto regarded as Triassic, adds weight to the view above expressed, that the *Clepsydrops* shales of Illinois belong either to the Triassic or Permian formations.

In 1878 he definitely asserted the Permian Age of the beds:[2]

The Texan genera of this group (Pelycosauria), so far as yet known, are about equally related to the Ural and South African types. The age of the former deposit is the Permian, which includes, according to Murchison, the Todtliegende and the Zechstein of Thuringia. The age of the South African beds is uncertain but is suspected by some authors to be Triassic, and by Owen to be Paleozoic. In discussing the *Clepsydrops* shales of Illinois, which had been referred to the Coal Measures by previous investigators, I left the question open as to whether they should be referred to the Triassic or the Permian formations. The evidence now adduced is sufficient to assign the formation, as represented in Illinois and Texas, to the Permian. Besides the saurian genera mentioned above, the existence of the icthyic genera *Janassa, Ctenodus,* and *Diplodus,* in both localities, renders this course necessary.

[1] *Am. Phil. Soc. Proc.*, 1877, Vol. XVII, p. 182. [2] *Ibid.*, p. 350.

THESES

1. The horizon of the *Clepsydrops* shales of Illinois and the corresponding beds in Texas is Permian.

Finally in 1879, in a comparison of the vertebrate horizons of Europe and America,[1] he gave the following table:

West Europe		North America
Thuringian Lodevian	Permian	*Clepsydrops* shale *Eryops* beds

And says:

The Permian vertebrate fauna which I discovered in Illinois and Texas exhibit close parallels, but not yet generic identity, in the two continents. Thus the American *Clepsydrops* and *Dimetrodon* are near to the *Deuterosaurus* of the Perm of Russia, and the *Lycosaurus* of the mountains of South Africa. The Texan genus *Pariotichus* may, with further information, prove to be identical with the *Procolophon* Ow. from the Tafelberg. Humeri of the type discovered by Kutorga in Russia and by Owen in South Africa, are found in North America, and the same remarkable type has recently been discovered by Gaudry in France. The peculiar type of Labyrinthodont vertebae described by me under the genus *Rhachitomus* from Texas has been discovered by Gaudry in France. The present indications are that close similarity between the faunae of this period in Europe and America will be discovered. Nevertheless up to the present time no representatives of the striking American forms, *Diadectes*, *Bolosaurus*, *Empedocles*, and *Cricotus*, have yet been found in any other continent (p. 34).

The oldest of these I have called the *Eryops* beds, from the most abundant genus of Labyrinthodonts which is found in it. They contain also abundance of other vertebrata, none of which are higher than the reptilia (order *Theromorpha*), with plants, mollusks, etc. They consist of sandstones, alternating with beds of red clay and coarse conglomerate and sphaerosiderite, etc. They are chiefly distributed in Northern Texas and Southern Indian Territory.

The *Clepsydrops* shale named by me in 1865 [misprint for 1875] forms a thin stratum, in southeast Illinois and southwest Indiana, consisting of black and rarely reddish carbonaceous shales and clays. These appear in some places to lie conformably upon the Coal Measures, to which they have been referred by previous geologists, but Collett, Gibson, and others have shown that it is unconformable over considerable areas. It does not belong to the Coal Measures (p. 52).

After this paper Cope consistently referred to the beds as Permian.

Reviewing the evidence cited above we find that the beds were so referred on—

1. The presence of reptiles.

[1] *Bull. Geol. and Geog. Survey of the Terrs.*, 1878–79, pp. 33–54.

2. The similarity of the *Poliosauridae*[1] and the *Clepsydropidae* to the reptiles from the known Permian of Europe and Africa.

3. The similarity of certain amphibians, especially *Eryops* and *Trimerorhachis*, to known Permian forms.

4. The presence of *Janassa*, *Ceratodus*, *Ctenodus*, *Diplodus*, and *Strigilina*.

5. He suggests the similarity of *Pariotichus* of Texas and *Procolophon* of South Africa.

These points will be discussed *seriatim*.

1. The argument from the presence of reptiles may be rejected at once as this is part of the question on trial. In a later paper (*Proc. Am. Phil. Soc.*, 1897, p. 88) Cope identifies one of his Permian reptiles from Illinois, *Isodectes*, in a form that he previously considered as an amphibian, *Tuditanus* from the Coal Measures of Linton, Ohio. So that he himself recognized the possibility of reptiles occurring below the Permian. The validity of this identification may be questioned, however.

2. The morphological similarity between the reptiles from the Illinois and Texas beds and reptiles from known Permian beds of Europe and Africa.

Cope depends on three points in particular.

a) The resemblance between *Clepsydrops* and *Lycosaurus* from the Permian of South Africa. This, with all other comparisons between the reptiles of the two continents (except perhaps the *Cotylosauria*) may be dismissed, as the forms have been shown to be so radically different (Diapsidan in North America and Synapsidan in South Africa) as to preclude any possibility of their use in indicating the contemporaneity of the beds.

b) The resemblance of *Clepsydrops* to *Deuterosaurus* of Russia. The skulls of *Deuterosaurus* and *Rhopalodon* have repeatedly been described, but their condition is such that no definite conclusions can be drawn, but the weight of evidence seems to be that they are nearer to the South African forms than to the North American.

c) The notochordal condition of the vertebrae, and the resemblance of certain humeri to humeri from the Permian of France. The first character cannot be considered as distinctive of the Permian;

[1] Case, *Publication 55*, Carnegie Institution, Washington.

it is characteristic of the most primitive type of reptiles and persists even to the present (*Sphenodon*).

The humerus mentioned by Cope was that of an amphibian or one of the *Diadectidae* and the French form was probably *Euchirosaurus*.

3. With regard to the amphibians the evidence is scarcely better. Cope emphasizes the rhachitomous character of the vertebrae and compares the condition of *Eryops* and *Trimerorhachis* with similar rhachitomous forms from the French Permian, the genus is not mentioned but it is evident that he had *Euchirosaurus* in mind. This character of the vertebrae comes nearer to being a determinant character than anything mentioned by Cope, but it is open to question because the same form of vertebrae occurs in the Carboniferous amphibian, *Dendrerpeton*.

4. The fishes mentioned by Cope have the distribution shown below:

Sagenodus—Carboniferous and Lower Permian.
Janassa—Carboniferous to Triassic.
Strigilina—A petalodont selachian of Carboniferous affinities.
Diplodus (*Orthocanthus*)—Carboniferous and Permian.

Evidently the fishes are of little more value than the amphibians and the reptiles.

5. The *Cotylosauria* common to North America and South Africa. The similarity of *Pariotichus* and *Procolophon* was suggested by Cope; this has been shown to be impossible, but Williston has very recently (*Journal of Geology*, Vol. XVI, No. 2, 1908, p. 148) attempted to show that *Labidosaurus*, a form very closely related to *Pariotichus*, is also very closely related to *Procolophon*.

However, even if this should be accepted, the presence of two distinct genera of this extremely primitive order could not prove the contemporaneity of two beds in such distant regions.

The evidence adduced by Cope is not sufficient to prove the Permian Age of the Illinois and Texas beds as against a possible Carboniferous Age.

It now remains to examine the evidence discovered since 1877. Undoubtedly Cope regarded much of this as directly confirmatory of his ideas.

1. There have repeatedly been suggestions that reptiles occur in beds below the Permian. Two examples suffice:

As cited above, Cope identified a reptile in the beds of Linton, Ohio. Following is a quotation from a letter written to the author by the late Dr. Baur, dated June 20, 1897:

> I have found out that *Hylonomus* Dawson, and *Dendrerpeton* Owen, and *Petrobates* Credner, are reptiles and not Stegocephalians. All these forms are Carboniferous with the exception of *Hylonomous*, which is also found in the Permian, and *Petrobates*, which belongs to the Permian alone. The vertebrae are elongate and biconcave, chevrons intercentral, ribs two-headed, long, slender, and bent. Teeth smooth, with large pulpa. Two sacral vertebrae, the second with small sacral rib. No cleithrum. Interclavicle T-shaped, clavicle slender. Ribs of caudal vertebrae bent backward. These forms are directly ancestral to the *Paleohateriidae*. *Microsauria* Dawson is the proper name for them. This fact, of course, makes the *Microsauria* the oldest reptiles, from which the *Paleohateriidae* and the *Rhyncocephalia* are directly developed.

The position taken in this letter was defended in the *Anatomischer Anzeiger*, Bd. IV, pp. 146–51.

2. The difficulty in distinguishing between the primitive reptilia and the amphibia has steadily increased by the discovery of intermediate forms, so that it is practically impossible to draw a line between the two today. The presence of a distinct parasphenoid bone distinguishes the amphibia, and in the Texas beds the presence of an entepicondylar foramen in the humerus distinguishes the reptiles, but this cannot, perhaps, be depended on as a general character of value.

We now proceed to the consideration of smaller groups.

Poliosauridae.—These may be related to the *Proterosauridae* rather more closely than to the *Pelycosauria* with which they have been described. *Proterosaurus* and *Paleohatteria* are typical members of the *Proterosauria* from the Permian.

Clepsydropidae.—No forms of this family occur in the Permian of Europe. *Ctenosaurus*, an aberrant, related form, is from the Bunter Sandstein and *Anomosaurus*, a doubtfully related form, is from the Muschelkalk.

Naosauridae.—A single species of this genus has been found in the Permian of Bohemia.

Pariotichidae.—No forms are known outside of the Texas beds.

Pareiasauridae.—Very doubtfully present in North America.

Among the amphibians—

Eryops.—Closely related in the rhachitomous character of the vertebrae to *Actinodon* and *Euchirosaurus* from the Permian of France.

Trimerorhachis.—No close relative of this form is known except in the character of the vertebrae.

Cricotus.—This resembles *Archegosaurus* in the embolomerous character of the vertebrae which occurs in the caudal series of *Archegosaurus* and throughout the column in *Cricotus*.

Dissorhophus and *Diplocaulus*.—Have no equivalents.

Crossotelos, Case.—This shows the characters of fringed dorsal and haemal spines in the caudal series such as occurs in *Urycordylus* and *Oesteocephalus* both from the Carboniferous.

The numerous smaller amphibians from Texas are so imperfectly known that it is impossible to make profitable comparisons with other forms.

Among the fishes—*Janassa* (*Thoracodus*), *Orthacanthus*, *Ctenodus*, *Ptyonodus* (*Sagenodus*), have been discussed above.

Didymodus.—Known from the Carboniferous of Europe.

Gnathorhiza.—Known from Texas only.

Sagenodus pertenuis, Eastman.—Known from the Permian of Russia (*fide* Broili).

Ectosteorhachis.—Known from Texas only.

We may now reject all the evidence furnished by the fishes except *Sagenodus pertenuis*, because they occur both in the Carboniferous and Permian, or because they do not occur outside of North America.

We may reject all of the amphibians except *Eryops* and *Cricotus* for the same reason.

We may reject all of the solid-roofed forms, *Cotylosauria* (*Chelydosauria*), *Pariotichidae*, etc., because they have no close relatives known outside of North America.

We may reject the *Clepsydropidae* as the only possible European representative is Triassic.

There remains only the family *Poliosauridae*, the genus *Naosaurus*, and *Sagenodus pertenuis*, worthy of consideration. *Sagenodus* has been identified from Texas (Eastman) and from Russia (Broili). The latter locality, the banks of the Lusa, a tributary of

the North Dwina, carries a fauna typical of the South African region.

As is well known, the genus *Naosaurus* occurs in the Permian of Bohemia.

The resemblance between the *Poliosauridae* and the *Proterosauridae* is in just such primitive and generalized characters as would persist from one formation to another.

The evidence for the Permian character of the beds rests then on the presence of a single genus, *Naosaurus*, common to the Permian of North America and Europe and on the community of many very primitive characters and numerous more specialized ones, which, however, reach either down into the Carboniferous below or up into the Triassic above.

CONCLUSION

1. The evidence from vertebrates is not sufficient to demonstrate the Permian Age of the beds in Illinois and Texas, they may reach down into the Carboniferous or they may extend upward into the Triassic.

2. There is no unlikelihood that reptilian life began in the Carboniferous. The evidence is rather affirmative than otherwise.

It is becoming more and more evident from the vertebrate paleontology that the Red Beds of North America and their eastern equivalents represent an enormous interval of emergence which may well have begun while Carboniferous (Pennsylvanian) forms still lingered in the waters and have continued until Triassic types were well established.

Reviews

Fourth Biennial Report of the State Geological Survey of North Dakota. By A. G. Leonard, State Geologist, E. J. Babcock, and C. H. Clapp. 312 pp., 37 pls., map. Grand Forks, 1906.

This volume continues the systematic descriptions of the economic possibilities of the state which have been published in previous years. North Dakota possesses extensive deposits of high-grade clays, as was well shown in the exhibits of the School of Mines at the St. Louis and Portland Expositions. The report contains chapters on the origin, chemistry, value, and physical properties of clays in general, and on the stratigraphy and economic geology of North Dakota clays in particular, together with a description of the methods of mining and manufacture now employed. H. H.

The Production of Gold and Silver in 1906. By Waldemar Lindgren, and Others. Advance chapter from *Mineral Resources* for 1906. U. S. Geol. Surv. 265 pp. Washington, 1907.

The total of these two metals mined in the United States, amounting in value to $132,630,200, showed an increase of over $10,000,000 for the year. Colorado, Alaska, and California were the chief producers of gold, and Montana, Colorado, and Utah of silver. H. H.

Iowa Geological Survey. Vol. XVII. Annual Report for 1906. 588 pp., 62 pls., 44 figs. Des Moines, 1907.

The major portion of this volume consists of a description of the quarry products of Iowa. Special stress is laid on cements and cement materials, and the careful general treatment of the properties, uses, and preparation of different grades of cement will be found valuable by economic geologists, and those commercially interested, in all parts of the country. H. H.

The Grenville-Hastings Unconformity. By Willet G. Miller and Cyril W. Knight. An extract from the Sixteenth Report of the Ontario Bureau of Mines, 1907. Part I, pp. 221–23.

The authors find themselves unable to agree with certain of the conclusions of the International Committee of 1906 in regard to southeastern

Ontario and the neighboring portions of Quebec. They object especially to the statement that the Hastings series is in reality only a less altered phase of the Grenville series. They have found that in eastern Ontario many of the limestones, conglomerates, and other fragmental rocks, which have been called the Hastings series, are much younger than the typical limestones of the Grenville series proper, and overlie the latter unconformably. The Grenville limestone, which rests in places on the ropy surfaces of Keewatin lavas, may be correlated with the Keewatin Iron Formation of the Lake Superior region; while the younger sedimentaries of the Hastings series are probably Huronian in age. H. H.

The Pre-Cambrian Volcanic and Intrusive Rocks of the Fox River Valley, Wisconsin. By WILLIAM HERBERT HOBBS AND CHARLES KENNETH LEITH. Bulletin of the University of Wisconsin, No. 158, pp. 247–78. 21 figs. Madison, May, 1907.

The Fox River Valley area of south-central Wisconsin presents several well-defined exposures of crystalline rocks of quite uniform chemical and mineralogical composition, but of varying textures. In passing outward from the granitic centers, intermediate textures and then surface volcanics are encountered, indicating the truncation of a volcanic region. The age of these rocks is certainly pre-Cambrian and probably Archean; for they occur as monadnocks projecting above the pre-Cambrian peneplain. The various rock types which are found in the area are fully described in the report. H. H.

Abandoned Shore Lines of Eastern Wisconsin. By JAMES WALTER GOLDTHWAIT. Wisconsin Geological and Natural History Survey, Bulletin No. XVII. 126 pp., 37 pls., 37 figs. Madison, 1907.

While the history of the greater Great Lakes which existed during the late stages of the Glacial period has been well blocked out by various investigators, detailed study of the ancient shore lines has been undertaken in only a few areas. This bulletin contains a very complete description of the old shore lines in Wisconsin, together with a review of all the previous work done in developing the history of the lakes, and a useful bibliography. Light is thrown on several controverted questions, and among the more important conclusions reached may be mentioned the following:

The 60-foot and 40-foot beaches of Lake Chicago seem to extend as far north as Sheboygan. It seems probable that the more northerly portions of them were

obliterated by the advance of the ice to the Manistee moraine. These higher beaches seem to have suffered little or no tilting.

The Lake Algonquin beaches seem to extend southward through Wisconsin with rapidly diminishing inclination south of Sturgeon Bay, becoming horizontal near Two Rivers, and encircling the southern half of Lake Michigan as the "Toleston" beach. This makes the Chicago outlet an outlet for Lake Algonquin at its highest stage.

The Nipissing water-plane seems to stand nearly horizontal along the whole Wisconsin shore—absolutely horizontal, and 10 or 15 feet above the lake, south of Manitowoc.

The elevation of the various beaches was determined by means of the wye level, thus reducing the chances for misinterpretation to a minimum.

H. H.

Some Characteristics of the Glacial Period in Non-Glaciated Regions. By ELLSWORTH HUNTINGTON. Bull. Geol. Soc. of Am., Vol. XVIII, pp. 351–88, pls. XXXI–XXXIX. New York, 1907.

This significant article is rendered particularly valuable because of the author's exceptional opportunities for the observation of arid conditions in two continents. It is evident, the whole earth considered, that fluctuations of the ice-edge were far from being the only effects of the climatic changes of the Pleistocene. In some of the now desert basins of central Asia are evidences of a surprising number of oscillations of lacustrine and arid conditions, some apparently coinciding with the known alternations of glacial and interglacial stages of the so-called Glacial period, and others preceding them.

H. H.

The Clays of Mississippi. By WILLIAM N. LOGAN. Mississippi Geological Survey, Bulletin No. 2. 250 pp., 42 pls., 14 figs. Jackson, 1907.

This bulletin contains chapters on the origin, classification, chemical and physical properties, and processes of manufacture of clays, on the properties and imperfections of brick, on the geology of Mississippi clays, and on the clay industries of the northern part of that state.

H. H.

A Theory of Continental Structure Applied to North America. By BAILEY WILLIS. Bull. Geol. Soc. of Am., Vol. XVIII, pp. 389–412. New York, 1907.

An analysis of the North American continent is taken to show that it may be resolved into a number of positive, or lighter, and of negative, or

denser, components. The negative elements have, because of the relatively greater density which they inherited from an original state, been able to force the positive into higher positions during much of geologic time, so that they are characterized by a greater thickness of fairly continuous sediments. The positive elements found their levels of isostatic adjustment to be higher, so that they have more often constituted our land masses. The original relations of these components to one another has been greatly modified by tangential pressure and igneous intrusions, making occasional readjustments necessary; though the continent as a whole has maintained its equilibrium with the exceptionally heavy oceanic segments. H. H.

Peat, Essays on Its Origin, Uses, and Distribution in Michigan. By CHARLES A. DAVIS. A part of the report for 1906 of the Michigan Geological Survey, pp. 105–360, pls. XIII–XXXI, figs. 2–20. Lansing, 1907.

The author has very properly taken up the study of peat from a botanical standpoint, though geological factors are by no means ignored. Michigan peat is composed largely of the remains of plants which grew below or near the water-level; sphagnum forms only shallow superficial deposits. The living plant society varies as the development of a bog advances, for the changed conditions created by one group of species may enable an invading group to obtain a foothold where it was unable to live before the introduction of the earlier group. We cannot, therefore, expect the flora at present living in a swamp to indicate the quality of the underlying peat. A peculiar type of structureless peat was found which consisted largely of algal remains with occasional diatoms and an abundance of the three-celled pollen grains of conifers. Under proper conditions peat of this character would form a deposit like the structureless cannel coals of the Carboniferous. Many uses for which peat could be profitably employed are pointed out. In Michigan, especially, peat coke might be made to bear a close relationship to the iron industry. H. H.

The California Earthquake of 1906. By DAVID STARR JORDAN and Others. San Francisco: A. M. Robertson, 1907.

This volume contains a collection of articles, partly of a semi-popular nature, by D. S. Jordan, J. C. Branner, G. K. Gilbert, S. Tabor, F. Omori, H. W. Fairbanks, and Mary Austin, which had previously appeared in various publications, together with a new essay by Charles Derleth, Jr., on the effects produced by the earthquake on structures and structural

materials. Both scientific and non-scientific readers will find much to interest them in it. The illustrations, of which the book contains 143, are noteworthy. H. H.

Contributions to the Geology of the Falkland Islands. By J. G. ANDERSSON. With 9 plates, and maps. Wissenschaftiche Ergebnisse der schwedischen Südpolar-Expedition, 1901–03, Band III, Lieferung 2. London: Dulau & Co.

In their deeply indented coast lines with numerous drowned valleys, the Falklands show a recent submergence of about 100 meters. During the ice age they stood at about their present height above the sea, while in pre-Glacial times they were somewhat higher and carried considerable rivers. A striking feature on East Falkland is the so-called "stone-rivers," which are level sheets of huge, angular bowlders streaming down the hillsides and reaching far out on almost level surfaces. This phenomenon is the product of solifluction, i. e., of gradual creep down the slopes of masses of waste saturated with water. Glacial action has not been the direct agent; for the islands seem never to have possessed a large ice cap. Thick peat deposits in this region furnish yet another instance of notable accumulations of vegetation in *cool*, moist climates. Devonian sandstone is found in the islands, resting on an Archean basement, while younger Paleozoic rocks are also present. H. H.

The Meteor Crater of Canyon Diablo, Arizona; Its History, Origin, and Associated Meteoric Irons. By GEORGE P. MERRILL. Reprinted from Smithsonian Miscellaneous Collections (Quarterly Issue), Vol. L, Part 4, pp. 461–98, pls. LXI–LXXV, figs. 124–29. Washington, January 27, 1908.

The author inclines strongly to the view that the peculiar topographic feature commonly known as Coon Butte owes its origin to the impact of a meteorite of unprecedented size. The crater, which is 4,000 feet in diameter and 500 feet deep, lies in a region of undisturbed sedimentary rocks which are horizontally bedded except in the immediate vicinity of the crater itself, where they show a strong quaquaversal dip. Extensive development work, now being carried on by a mining company in the field, fails to substantiate the theory that volcanic action has been the factor involved, but shows that the disturbance was essentially superficial. Microscopic and megascopic studies of the fragmental materials in and about the crater indi-

cate the action of a force which caused considerable crushing, and which may have been due to meteoritic impact, followed, perhaps, by an intense explosion. H. H.

The Geology of the Compostela-Danao Coal Field. By WARREN D. SMITH. From the *Philippine Journal of Science*, Vol. II, No. 6, pp. 377–403. 15 pls., 3 maps. Manila, 1907.

The area mapped covers 36 square miles of mountainous country on the Island of Cebu which is quite generally underlain with coal, probably of Eocene age. In the area under consideration there are indications of the presence of several million workable tons of coal, and these are now being partially developed. The lack of suitable timber to support a rather weak roof, and the high inclination of the beds offer great, but not insuperable, difficulties for profitable mining. An igneous base underlies the region and on it were deposited the coal measure shales, and the sandstones and conglomerates of the Eocene. The Oligocene and Miocene are represented by interesting deposits of limestone. H. H.

Meteorite Studies, II. By OLIVER CUMMINGS FARRINGTON. Field Columbian Museum, Publication 122. 18 pp., 14 pls. Chicago, 1907.

Complete descriptions are here given of a number of meteorites and of the conditions under which they were discovered. Photographs of the rocks and plans of various localities add to the clearness of the exposition. It will be remembered that the same author gave an excellent summary of the constituents, structure, and theoretical origins of meteorites in this Journal, Vol. IX, pp. 51, 174, 393, 522, and 623. H. H.